

THE EFFECT OF WEATHER ON MICROWAVE
PROPAGATION

A THESIS

Presented to
the Faculty of the Division of Graduate Studies
Georgia Institute of Technology

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Physics

by

Frank Burkhead Brown, Jr.

June 1950

Crossland

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PROPAGATION

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Date Approved by Chairman

June 1, 1950

TABLE OF CONTENTS

CHAPTER	PAGE
I. THE EFFECT OF WEATHER ON THE M-GRADIENT.....	1
II. THE EFFECT OF THE M-GRADIENT ON THE TRANSMITTED SIGNAL.....	18
III. STATISTICAL ANALYSIS.....	28

LIST OF TABLES

TABLE	PAGE
I. Saturated Vapor Pressure of Water in Millibars.....	8
II. The Relative Importance of Temperature and Moisture On the M-Gradient.....	10
III. The M-Gradient Through a Satu- rated Layer of Air Having a Moist Adiabatic Temperature Lapse Rate.....	11

LIST OF FIGURES

FIGURE	PAGE
1. Grazing Ray Trajectories for Different M-Gradients..	1(a)
2. Ray Refraction Over Curved Earth.....	2
3. The M-Gradient Under Typical Stratification.....	17(a)
4. Interference Due to Surface Reflection.....	20
5. Interference Due to Elevated Inhomogeneities.....	22
6. (a) Received Signal Strength Under Typical Weather Conditions.....	23(a)
(b) Received Signal Strength Under Typical Weather Conditions.....	23(b)
7. Weather Flow Chart and Hourly Signal Variations for 5-8 August 1948.....	28(a)
8. Instantaneous Received Signal Strength-X Band.....	30(a)
9. Instantaneous Received Signal Strength-S Band.....	30(b)
10. Instantaneous Received Signal Strength-L Band.....	30(c)
11. Effect of Ducts on Received Power at X Band during Period 27 July - 9 August 1948.....	34(a)
12. Effect of Wind Speed on Received Power at X Band during Period 18 October - 10 November, 1947.....	34(b)
13. Effect of Heavy Rain Showers on Received Power at X Band during July 1948.....	34(c)

LIST OF FIGURES

(continued)

FIGURE	PAGE
14. Maximum Hourly Fluctuations of Signal Strength under Fog Conditions.....	35(a)
15. Maximum Hourly Fluctuations of Received Signals at X Band.....	35(b)
16. Maximum Hourly Fluctuations of Received Signals at S Band.....	35(c)
17. Maximum Hourly Fluctuations of Received Signals at L Band.....	35(d)

THE EFFECT OF WEATHER ON MICROWAVE PROPAGATION

CHAPTER I

THE EFFECT OF WEATHER ON THE M-GRADIENT

I. ANOMOLOUS BEHAVIOR OF RECEIVED SIGNAL

During the recent war, the unpredictable behavior at certain times of radar and microwave radio signals became an object of intensive study.

Ordinarily, if a microwave signal were transmitted over a given path the received power could be predicted from a knowledge of the distance, the terrain and the characteristics of the equipment involved. The effects of the terrain variations were, of course, important. It was well known, for example, that the intensity of a received signal dropped off rapidly below the "radar horizon", and that diffuse reflection or scattering of radiation by irregular terrain prevented the pronounced two path interference which had been noted in propagation over water.

However, many of the observed effects could not be written off simply as terrain reflection or scattering. Abrupt fades in signal strength were often noted, sometimes amounting to a drop in power of twenty to thirty decibels—about $1/100$ to $1/1000$ of the predicted value. At other times strong signals were received at points well below the horizon. These signals, according to the electronic circuit equations and terrain considerations only, could not have been received at all.

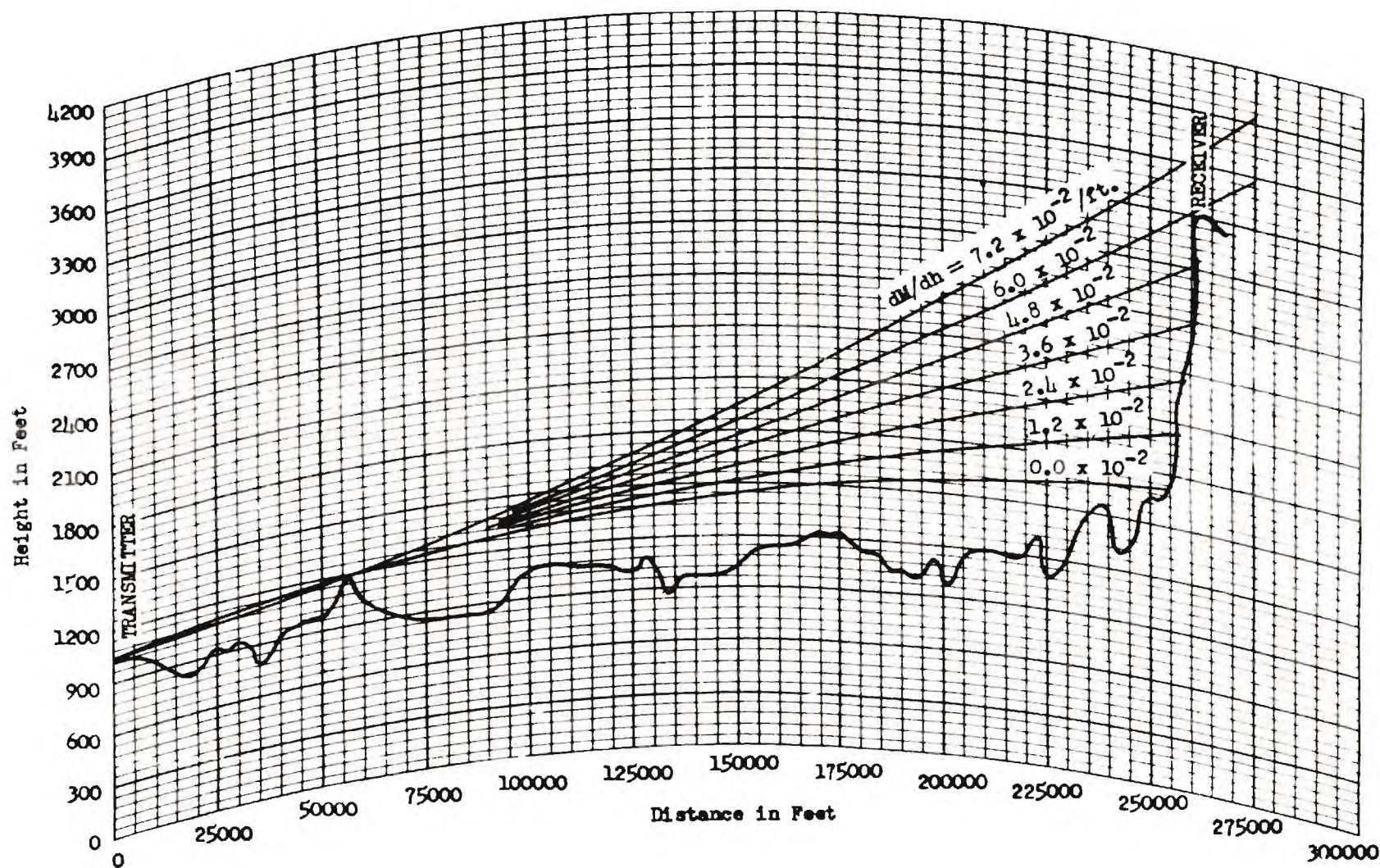


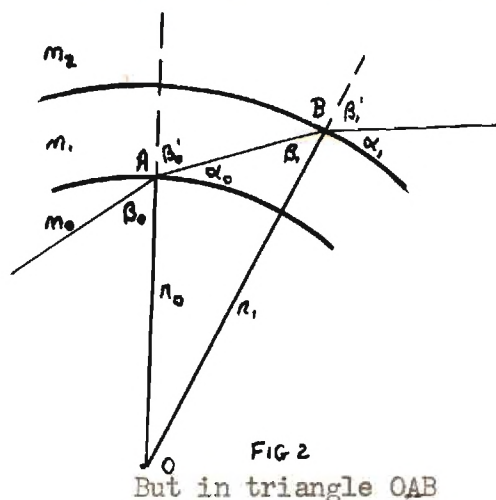
Figure 1.
Grazing Ray Trajectories for Different M-Gradients
(True Earth Radius)

These variations in the intensity of the received signal were due to changes in the index of refraction of the atmosphere.

II. THE INDEX OF REFRACTION OVER A CURVED EARTH

Snell's law of refraction over a curved earth may be derived as follows¹:

Considering an atmosphere stratified vertically above the earth, with layers of index of refraction n_0 , n_1 and n_2 as shown:



$$(a) n_0 \sin \beta_0 = n_1 \sin \beta'_0$$

$$(b) n_1 \sin \beta_1 = n_2 \sin \beta'_1 \text{ etc.}$$

Multiply the first of these equations by r_0 , the second by r_1 , etc., obtaining:

$$(a) n_0 r_0 \sin \beta_0 = n_1 r_0 \sin \beta'_0$$

$$(b) n_1 r_1 \sin \beta_1 = n_2 r_1 \sin \beta'_1 \text{ etc.}$$

$$\frac{\sin \beta'_0}{r_1} = \frac{\sin \beta_1}{r_0} \text{, etc.}$$

so that

$$n_0 r_0 \sin \beta_0 = n_1 r_1 \sin \beta_1 = n_2 r_2 \sin \beta_2 \text{ etc.,}$$

or, in general, for an index changing continuously with height,

$$n r \cos \alpha = n_0 r_0 \cos \alpha_0$$

If we choose r_0 as a , the radius of the earth, and choose $r = a+h$, this may be written

¹ Columbia University NDRC Rpt. WPG 5 Sept. 1945.

$$n(1 + h/a) \cos \alpha = n_0 \cos \alpha_0$$

Since h/a is very small and n is very near unity, then $n(1 + h/a)$ is very nearly equal to $n + h/a$, and we have, for Snell's law over a curved earth,

$$(n + h/a) \cos \alpha = n_0 \cos \alpha_0 \quad (1)$$

Now M , the modified index of refraction, is defined by the relation

$$M = (n + h/a - 1)10^6$$

and $M_0 = (n_0 - 1)10^6$. Hence one M -unit represents an excess of refractive index above unity of one-millionth.

From (1) above, it follows that

$$(10^{-6}M + 1) \cos \alpha = (10^{-6}M_0 + 1) \cos \alpha_0$$

and from the definition of M , above,

$$10^{-6} dM/dh = dn/dh + 1/a$$

where dM/dh represents the rate of change of the modified index with height, and is referred to as the M -Gradient.

Since for nearly horizontal rays $dn/dh = -1/\rho$, where ρ is the true curvature of the ray in the atmosphere, then

$$10^{-6} dM/dh = 1/a - 1/\rho \quad (2)$$

is the relative curvature of a ray with respect to the earth.

Thus if the M -value through a given layer is constant vertically, that is $dM/dh = 0$, the horizontally emitted ray will have the same curvature as the earth and will then travel at a fixed height above the earth. If dM/dh is negative the ray will be bent toward the surface of the

earth and trapping will result. If dm/dh is positive the curvature of the ray will be less than that of the earth and the ray will be deflected upward away from the earth. Figure 1 indicates the behavior of a horizontally emitted ray under various conditions of stratification.

III. THE RAY EQUATIONS

The equations of the ray paths are readily obtained² from equations (1) and (2) above, and the resultant relation

$$\alpha^2 = (dh/ds)^2 = \alpha_1^2 + 2b(h-h_1) \quad (3)$$

may be used to calculate the theoretical path of a ray through any given stratification. Here α is the angle which the ray makes with the horizontal, s is the horizontal distance from the transmitter to a point on the ray, h is the height above mean sea level and $b = 10^{-6} dm/dh$.

Apparently, from the foregoing summary it should be possible to predict the behavior of the transmitted ray. If, for example, we assumed the presence of a ground based stratum through which dm/dh was negative, and if we assumed that the stratum included the transmitter but lay below the receiver, then a horizontally emitted signal would be trapped and except for irregular leakage would be held entirely beneath the receiver. This leakage, however, is very pronounced due to the tremendous number of meteorological and geographic irregularities encountered. Also, a ray entering the duct at any angle greater than one or two degrees from the horizontal may not be trapped at all or even affected appreciably.

² Columbia University NDRC Rpt WPG 5 Sept. 1945.

The integrated form of equation (3) gives

$$b(s-s_1)^2 + 2\alpha_1(s-s_1) - 2(h-h_1) = 0 \quad (4)$$

This equation represents a family of parabolas when the rays are plotted using flat-earth coordinates. If the value of $b = 10^{-6} dM/dh$ is positive the parabolas are concave upward, and if b is negative the parabolas are concave downward. In a vertically stratified atmosphere each ray will consist of a number of sections of parabolas, the equations of the parabolas changing from layer to layer. If the M -gradient is negative and the thickness of the layer is sufficient, the ray will reach the apex of the parabola for which dh/ds is zero, and will be internally reflected or trapped. If the M -gradient is positive, on the other hand, the parabolas will be concave upward and the ray will be bent to a greater height. A ray may thus be traced through either a homogeneous or a stratified atmosphere, provided the M -gradient is known at all points. This of course implies a complete knowledge of all weather elements, vertically and horizontally. The effort to develop a point-to-point analysis of the effect of weather on microwave propagation thus involves the accumulation of as much accurate meteorological data as possible, and coordination of that data with received signal strength records made at the same time.

IV. VARIANTS AFFECTING THE INDEX OF REFRACTION

The index of refraction of air is a function of its density and its water vapor content. At times, particularly during periods of convective action and mixing, the moisture and temperature lapse rates approach a uniform value which we may regard as "standard", or typical

of the particular air mass involved. These standard conditions are most likely to be reached in the mid-afternoon of a clear day, when surface heating has brought about considerable vertical air transport, or when high winds tend to lift and mix the various elements.

These uniform lapse rates of temperature and moisture tend to bring about a uniform change in the index of refraction with height, which we may define as a standard M-gradient.

Due to the varying temperature and moisture conditions associated with different air masses, the rate of change of M with height in a so-called "standard" atmosphere would be expected to change slightly from season to season. During any one season and in a given locality, however, it is a fixed and reasonably reliable criterion.

Under certain conditions, when the mixing factors are relatively weak, strata are likely to form-- layers in which the M-gradient differs sharply from the gradient in a standard atmosphere.

For convenience and for consistency the following terminology is defined:

- (a)substandard layer: a stratum in which the M-gradient is .150 M-units per meter or greater.
- (b)standard layer: a stratum in which the M-gradient lies between .100 and .150 M-units per meter.
- (c)superrefractive layer: a stratum in which the M-gradient is less than .100 M-units per meter, a category which includes the duct.
- (d)duct: a stratum through part of which the M-gradient is negative, M decreasing with height.

V. THE MODIFIED INDEX OF REFRACTION UNDER SATURATED CONDITIONS

The index of refraction, n , may be expressed by the empirical formula³:

$$(n-1)10^6 = \frac{79 P}{T} + \frac{3.8 \times 10^5 e}{T^2} \quad (5)$$

where P is the atmospheric pressure in millibars, e is the water vapor pressure in millibars and T is the absolute temperature in degrees Kelvin. Obviously the changes of n with altitude are very small, since n only varies from about 1.0004 at sea level to 1.0000 in vacuum. The use of the modified index of refraction is convenient since it is expressed as a whole number instead of as a very small fraction, such as $(n-1)$.

From the definition of M on page 3 and from equation (5) we have:

$$M = \frac{79 P}{T} + \frac{3.8 \times 10^5 e}{T^2} + 10^6 (h/a) \quad (6)$$

Then

$$dM/dh = \frac{79}{T^2} (P + \frac{9600 e}{T}) dT/dh + \frac{3.8 \times 10^5}{T^2} de/dh + \frac{79}{T} dP/dh + 0.157$$

But under standard conditions, at levels up to two or three kilometers,

$$\frac{79}{T} dP/dh = - \frac{79}{293} (.113) = - .032$$

³ Charles R. Burrows and Stephen S. Attwood, Radio Wave Propagation. The Academic Press, Inc., New York 1949. 548 pp.

and

$$dM/dh = A dT/dh + B de/dh + 0.125 \quad (7)$$

where

$$A = -\frac{79}{T^2} \left(P + \frac{9600 e}{T} \right)$$

and

$$B = \frac{3.8 \times 10^5}{T^2} .$$

Thus the M-gradient, in M-units per meter, is expressed in terms of the temperature lapse rate in degrees Kelvin or Centigrade per meter, and the moisture lapse rate in millibars per meter.

Now, in saturated air the water vapor pressure is a function of the temperature as the accompanying table indicates.⁴

TABLE I.

Saturation Pressure of Water Vapor, Millibars

Deg C	0	1	2	3	4	5	6	7	8	9
-10	2.86	2.64	2.44	2.25	2.07	1.91	1.75			
- 0	6.11	5.68	5.27	4.89	4.54	4.21	3.90	3.62	3.35	3.10
+ 0	6.11	6.57	7.06	7.58	8.13	8.72	9.35	10.02	10.73	11.48
10	12.28	13.13	14.02	14.98	15.98	17.05	18.18	19.38	20.64	21.97
20	23.38	24.87	26.44	28.09	29.84	31.68	33.61	35.65	37.80	40.06
30	42.45	44.93	47.55	50.31	53.20	56.23	59.42	62.76	67.26	69.92
40	74.10	77.79	82.00	86.40	91.01	95.84	100.87	106.1	111.6	117.4

The equations

$$e_s = 14.3 e^{.046 t} - 0.22 t - 8.2 \quad (8)$$

and

$$de_s/dt = 0.66 e^{.046 t} - 0.22 \quad (9)$$

⁴ H.H. Landolt and R. Bornstein, Physikalisch-chemische Tabellen, 5th ed., p. 1314, Verlag Julius Springer, Berlin, 1923.

may be fitted to these data over the temperature range from zero degrees to thirty degrees Centigrade, where the saturation vapor pressure, e_s , is given as a function of temperature in degrees Centigrade, t . e is the base of natural logarithms. While only approximate, these equations hold within 1% over this temperature range.

Since

$$de_s/dh = (de_s/dt)(dt/dh)$$

we have, combining equations (7), (8) and (9) above:

$$dM/dh = (A' + B') dt/dh + 0.125 \quad (10)$$

where

$$A' = -\frac{79}{T^2} \left[P + \frac{9600}{T} (14.3 e^{.046 t} - 0.22 t - 8.2) \right],$$

$$B' = \frac{3.8 \times 10^5}{T^2} (0.66 e^{.046 t} - 0.22)$$

and

$$T = 273^\circ + t$$

A change in temperature in a saturated stratum of air is thus seen to affect the M-value in two ways. The A' term in equation (10) represents the rate of change in M-units per meter produced by the temperature gradient itself, measured in degrees Centigrade per meter. The B' factor represents the rate of change in M-units per meter produced by the resultant gradient of vapor pressure, itself dependent upon the rate of temperature change in saturated air.

An examination of equation (10) indicates that the relative weight of these two terms depends upon the temperature itself. Thus in a fog or cloud layer, the distribution of moisture is more important than the distribution of temperature in determining the M-gradient, in the ratio indicated in Table II.

TABLE II

Relative Importance of Temperature and Moisture on the M-Gradient

Mean Temperature of Layer, °C.	Relative Importance of Moist- ure term to Temperature term	
	1000 mb	900 mb
-10	0.85	0.95
0	1.72	1.86
10	2.86	3.06
20	3.91	4.14
30	4.50	5.18

It will be apparent that the greater the temperature of a layer becomes, the greater becomes the relative importance of the moisture distribution through that layer. At temperatures below about -8°C the temperature distribution would be relatively of greater importance than the moisture distribution. Under non saturated conditions this relative importance would be decreased by an amount dependent upon the relative humidity.

Let us assume that the temperature lapse rate through a saturated layer of air is equal to the moist adiabatic lapse rate. This lapse rate may be closely approximated, from -10°C to 20°C , by the expression below, fitted to the aerogram of the Aerological Committee of the International Meteorological Organization:

$$dt_w/dh = - \frac{6.6 - 0.1 t}{1000} ^{\circ}\text{C per meter} \quad (11)$$

where t is the mean temperature of the layer in degrees Centigrade.

Combining equations (10) and (11) we obtain for the M-gradient,

$$dM/dh = (A' + B') \left(- \frac{6.6 - 0.1 t}{1000} \right) + 0.125 \quad (12)$$

Thus, through a saturated layer with a moist adiabatic lapse rate, the M-gradient depends upon the mean temperature of the layer, as indicated in Table III.

TABLE III.

The M-Gradient Through a Saturated Layer of Air
Having a Moist Adiabatic Temperature Lapse Rate

Mean Temperature of Cloud or Fog, °C.	M-Gradient, M-units/meter	
	1000 mb	900 mb
-10	0.126	0.125
0	0.119	0.118
10	0.111	0.110
20	0.104	0.103
30	0.097	0.096

Obviously warmer layers of fog or cloud would tend to be more nearly superrefractive than would cold layers.⁵

Although under certain conditions visible condensation may occur with the relative humidity less than 100%, this is exceptional and in any case would merely result in a slight decrease in the relative importance of the moisture term of equation (10).

Of much greater importance, the temperature lapse rate through the fog or cloud layer, far from being moist adiabatic, may be isothermal or may even be negative, with the temperature increasing with height.

Let us examine equation (10) under the assumption that the relative humidity remains 100% through the layer. It is evident that if the layer is isothermal, that is $dt/dh = 0$, then dM/dh will be 0.125 M-units/meter. If the temperature increases with height then the magnitude of the B' term will increase with height at a faster rate than the magnitude of the A' term, so that dM/dh will be greater than 0.125 M-units/meter, possibly highly substandard.

⁵ It is here assumed that the water vapor is in liquid state even below 0°C., and the vapor pressure is taken with respect to a surface of water. If freezing is also taking place in the layer, the lapse rate would become less due to the addition to the air of the latent heat of fusion, and the resultant M-gradient would be slightly higher.

The smallest M-gradient possible under saturated conditions will occur when dt/dh is moist adiabatic, since if this lapse rate is exceeded the density of the air will increase with height and instability will result. When dt/dh lies between 0 and the moist adiabatic, dM/dh will lie between 0.125 M-units/meter and the value called for in Table III. The effect of any deviation from a moist adiabatic lapse rate would then be to modify or prevent the formation of a superrefractive stratum.

Since an adiabatic lapse rate involves a certain amount of free vertical motion of the air due to convective action, wind or turbulence, and since fog and stratiform clouds are associated with relatively stable conditions, it follows that the likelihood of these layers becoming superrefractive is very small. In the particular case of a radiation fog, brought about by night-time cooling near the ground, a temperature inversion is likely which would tend to make the fog layer highly substandard.

VI. THE M-GRADIENT IN UNSATURATED AIR

Let us now examine the M-gradient through a layer of unsaturated air in which the temperature lapse rate is negative. This is a set of conditions often found in low-level strata which are cooled by nocturnal radiation.

Consider, for example, a layer of air 100 meters thick which has the following characteristics:

- (a) a vertical increase of temperature where $dt/dh = .03^{\circ}\text{C}/\text{meter}$.
- (b) a decreasing relative humidity from 100% at the bottom of the layer to 10% at the top of the layer.
- (c) a temperature of 20°C . at the bottom of the layer and 23°C . at the top of the layer.

(d) an atmospheric pressure of 1000 mb at the base of the layer.

Then since

$$\begin{aligned}\Delta e &= e_{100} - e_0 = 28.09(.10) - 23.38(1.00) \\ &= -20.47 \text{ mb}\end{aligned}$$

and

$$de/dh = - .205 \text{ mb/meter}$$

equation (7) gives a value of -0.800 M-units/meter for the M-gradient at the base of the layer.

Here the effect is exaggerated, but we have the situation of a vertical temperature rise accompanying a decreasing relative humidity to produce an intensely superrefractive stratum. If the relative humidity had held constant at, say, 80% through the layer, dM/dh would become $+0.173$ M-units/meter, more substandard than the value from Table III for clouds and fogs. Thus the superrefractive layer produced here is due almost entirely to the rapid decrease of moisture with height.

Further, consider a series of conditions where the relative humidity is constant with height: first let us assume it to be constant at 100%, then at 80%, then at 60%, etc. We find that the moisture term of equation (10) becomes relatively of less and less importance until, for a certain critical value of relative humidity (from 54% for a 0°C layer to 19% for a 30°C layer), the temperature and moisture factors will be of equal weight and dM/dh will be 0.125 M-units/meter. Below this value of relative humidity the temperature term would predominate over the moisture term. However, the maximum possible temperature lapse rate is 10°C per kilometer, the dry adiabatic lapse rate. It follows that a change of temperature alone, with vapor pressure constant, could only change dM/dh from 0.125 to about 0.147 M-units/meter. Or, if the temperature rose at a rate of 10°C per kilometer,

dM/dh would decrease to 0.103 M-units/meter. Further, in order to account for a negative M-gradient by temperature alone, the temperature would have to rise at the rate of about 1°C for every 20 meters of height, which, though possible under intense stratification, is usually prevented by wind and turbulence. Thence, in order for a given stratum to act as a duct, a decreasing relative humidity with height is usually a necessity.

VII. EFFECT OF TYPICAL METEOROLOGICAL STRATIFICATION ON THE M-GRADIENT

We are now in a position to predict what the modified index of refraction should be under certain characteristic weather conditions.

1. Radiative Cooling. As nocturnal cooling progresses a strong duct condition develops since surface cooling is involved and since more of the moisture is near the ground. A temperature rise and a vapor pressure drop with height are both conducive to the formation of a superrefractive stratum. In particular the upper boundaries of the temperature inversion are likely to be superrefractive since the inversion of temperature there will act as a "lid", preventing vertical transport of moisture above this level. An air parcel moving upward into this temperature inversion and cooling adiabatically as it rose would be denser than the surrounding air and would tend to drop back.

As the cooling near the surface continues fog is likely to form. Since fog would tend to prevent further radiation loss, the temperatures near the ground will rise and the inversion will become less intense. There is evidence to indicate⁶ that as the fog layer deepens the temperature

⁶ Georgia-Tech to Lost Mountain Operation, low level soundings, July and August 1949.

lapse rate through it becomes nearer isothermal. Since the air is saturated, this would mean an increasing vapor pressure with height and a substandard M-gradient through the fog itself, probably accompanied by a superrefractive layer above due to the abrupt decrease in vapor pressure above the temperature inversion "lid".

2. Frontal Fog. Caused by moist air moving over cooler ground or by mixing of two air masses, frontal fog is usually associated with low hanging clouds and often accompanied by rain or drizzle. This tends to render the temperature lapse rate much closer to the moist adiabatic than is the case for radiation type fogs. The M-gradient through the fog itself is therefore very nearly standard. Above the layer the air remains moist, instead of the sudden moisture decrease noted above for radiation fogs. Thus, although mild superrefraction may occur above frontal fogs, the probabilities favor a standard M-gradient.

3. Stratiform Clouds. Here the structure is very similar to radiation fog, with a substandard M-gradient through the cloud and a drop in moisture creating a slightly superrefractive stratum above it. Beneath the cloud the relative humidity increases nearly uniformly to 100% at the base of the cloud. Due to turbulent mixing, the air beneath the cloud has an approximately standard M-gradient. Through the cloud itself the M-gradient may be determined as in the case of radiation fog. Since the moisture content of the air at an altitude is usually less than that at the ground due to the lower temperatures, the stratification described here is usually not as intense as it is in the case of low-level fogs.

4. Cumuliform Clouds. Cumuliform clouds being of the convective type, the temperature lapse rate under them will be at or near the dry adiabatic, and the M-gradient near standard. Through the clouds dt/dh

will be nearly moist adiabatic, from $-6^{\circ}\text{C}/\text{km}$ to $-4^{\circ}\text{C}/\text{km}$ depending on air mass conditions. Thence the M-gradient through the cloud will be in very close agreement with the value obtained from Table III. A slight super-refractive tendency may exist above the cloud, especially if its vertical development has been limited by a temperature inversion "lid". This tendency would usually be weak, however, due to the reduced vapor pressure present at high levels.

5. Haze. There are two distinct forms of haze, entirely different in their origins. Neither form has a direct effect on the M-gradient or on the transmitted signal except possibly for some random scattering. However, haze may serve to indicate the presence of stratification which would not otherwise be apparent.

The drop in visibility produced by one form of haze is due to the scattering action of small hygroscopic nuclei in the air, often trapped beneath a temperature inversion in stable air, and aggravated by the presence of smoke and fog. The top of this haze layer is then usually a temperature inversion, and thus represents a discontinuity in the M-curve. Often this level will be an air mass boundary.

Another type of haze condition is noted when the air may be free of visible dust and moisture, especially on hot days. This is often called "optical haze", and is due to the unequal refraction of light passing through air of varying density. These conditions are more likely to be associated with unstable air, since large scale vertical air currents are more likely then. Optical haze is likely to build up suddenly on hot days, and is usually a prelude to thundershower activity. At any rate, the presence of optical haze indicates a lack of uniform stratification since it is associated with strong convective action. Both forms of haze

can and usually do occur under unsaturated conditions.

6. Moist Ground. The behavior of the M-gradient over a wet surface is typified by the gradient over the ocean and to a lesser extent by the gradient over the tops of many clouds and over ground recently wet by rain. The most pronounced effect at the ground occurs when the air mass over the ground is relatively dry, since the duct is caused by the extremely rapid drop in vapor pressure in the first few feet. This type of duct, though often intense, is never very deep. It is however accompanied by large scale horizontal inhomogeneities in the air, particularly under shower activity, due to the spotty coverage. These inhomogeneities probably affect the signal more than the duct itself.

7. Air Mass Discontinuities Aloft. Typical of this category are warm front inversions aloft and subsidence inversions. In the case of all subsidence inversions, and in the case of overrunning warm air which is relatively dry, a strong superrefractive or duct condition exists due to the combined temperature rise and vapor pressure drop with height.

In many other frontal conditions, however, the boundary may be a substandard stratum. If, for example, moist, warm air from the Gulf of Mexico overruns cold dry air from Canada, the frontal zone will be strongly substandard due to the increase in moisture with height which will more than offset the effect of the increase in temperature on the M-gradient.

Figure 3 illustrates some of the more typical forms of stratification encountered, with the M-gradient to be expected in each case as described above. Actual M_e curves from several specific periods are also included for reference.

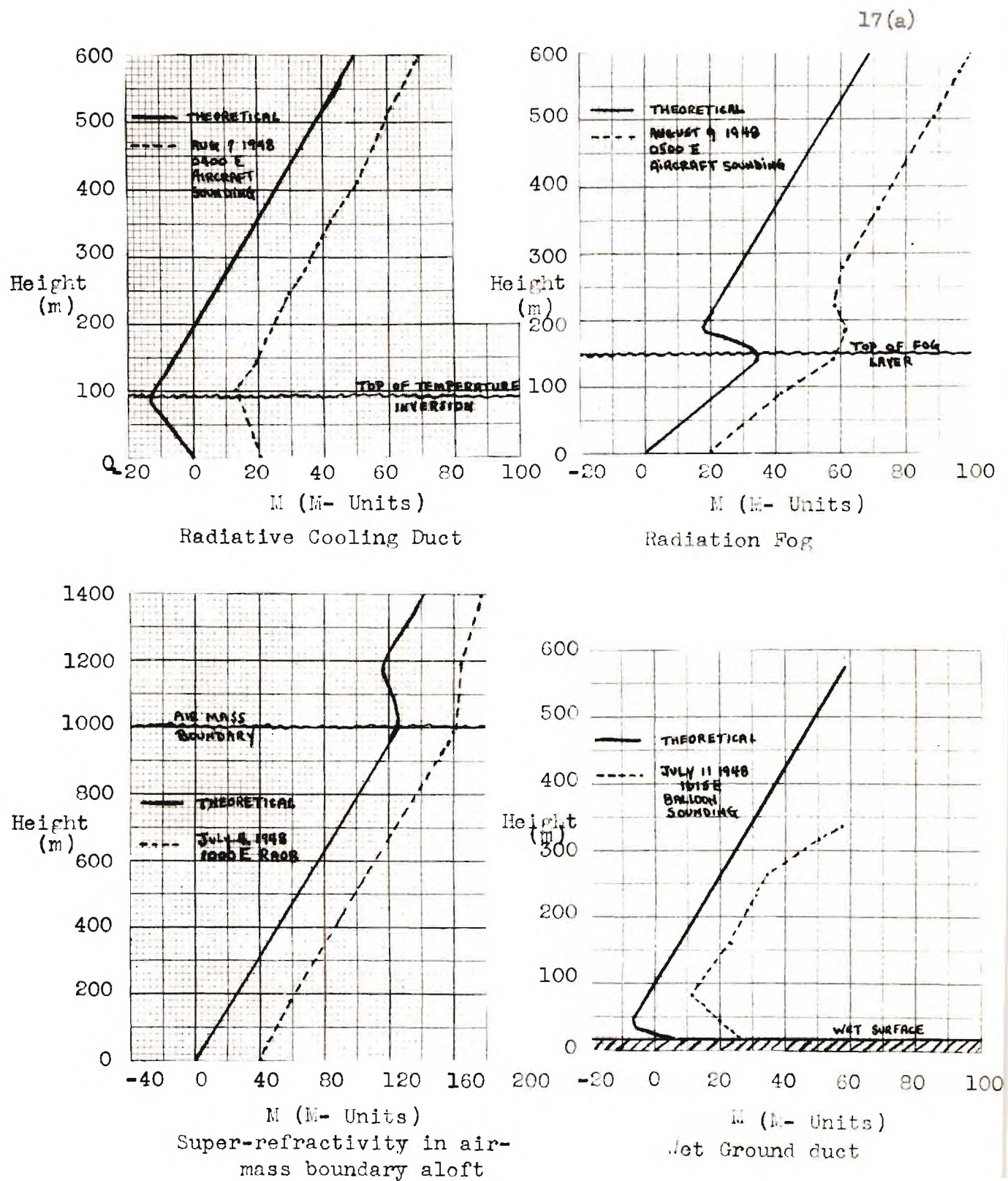


Figure 3.

The M Gradient Under
Typical Stratification

CHAPTER II

THE EFFECT OF THE M-GRADIENT ON THE TRANSMITTED SIGNAL

I. THE GEORGIA TECH TO MOUNT OGLETHORPE OPERATIONS

In order to investigate some of the effects of weather on microwave propagation, a transmission path was set up at Georgia Institute of Technology and a series of simultaneous signal strength measurements and meteorological soundings were made. Transmitters were installed on the roof of the Physics Building at Georgia Tech at an elevation of 1040 ft above mean sea level, and receivers were placed on Mt. Oglethorpe, some 50 miles north of Georgia Tech and 3300 ft above mean sea level, well above the radar horizon. A profile of this path is shown in Figure 1, the vertical scale being greatly exaggerated to indicate terrain irregularities.

Transmission was then begun on three frequencies:

- X Band at 3 cm wave length, 9400 mc.,
- S Band at 10 cm wave length, 2860 mc., and
- L Band at 23 cm wave length, 1310 mc.

Propagation data were collected during the following periods of operation:

1. August 9 to August 30, 1947
2. October 11 to November 21, 1947
3. January 25 to February 1, 1948
4. May 28 to June 1, 1948
5. June 29 to July 12, 1948

6. July 27 to August 9, 1948

The X and S Bands were in use on all six operations and the L Band was in operation on the last five.

Since the Oglethorpe path was well above the radar horizon it would be expected that, if there had been no atmosphere present, the received signal would be extremely steady and would remain near the "calculated free space" value. This calculated signal strength level is obtained from such measured equipment parameters as receiver and transmitter gains, and from a consideration of the distances involved. The presence of the atmosphere serves to modify this free space signal by introducing meteorological factors which change the index of refraction of the air and by introducing certain attenuating factors such as rain, snow and fog.

Weather data for these operations were compiled from several sources. Surface observations were made periodically from both the transmitting and receiving sites. Balloon soundings were made from a point near the middle of the propagation path, up to altitudes of 300 to 600 meters. Also, an airplane equipped with wet and dry bulb psychrometers was used for more extensive soundings. In addition, radiosonde soundings, surface observations, synoptic maps and upper wind analyses from the Atlanta Weather Bureau were utilized.

Still the useful information was somewhat spotty. The accuracy of the balloon soundings was not always dependable. While the time-lag of the instruments was not great, the time necessary for completing a given sounding was appreciable, and the results were sometimes doubtful. The accuracy of the radiosonde data was limited by a time lag in the response of the thermal elements which could cause it to miss a low lying stratum

altogether. In addition, the Atlanta Weather Bureau observations, while usually reliable, were representative of air mass conditions some 30 miles south of the center of the path.

Combining the most reliable data obtainable, fairly complete observations of cloud height and cover, rainfall, fog, wind and temperature were utilized.

II. INTERFERENCE

Of considerable importance also in its effect on the signal is the possibility of two-path or multiple-path interference causing a fluctuation in the received signal level. This effect of course would not be indicated by the ray tracing technique alone, but would involve consideration of the phase difference between the combining elements.

Consider two rays emanating from the transmitter, one traveling direct to the receiver, the other being reflected from the ground and reaching the receiver by path ABC (see Figure 4). Due to the difference in length of the two optical paths, and possibly a phase change at the point of reflection, the rays may arrive at the receiver out of phase, creating a null if of the same amplitude. Or they may arrive in phase, thus reinforcing the received signal.

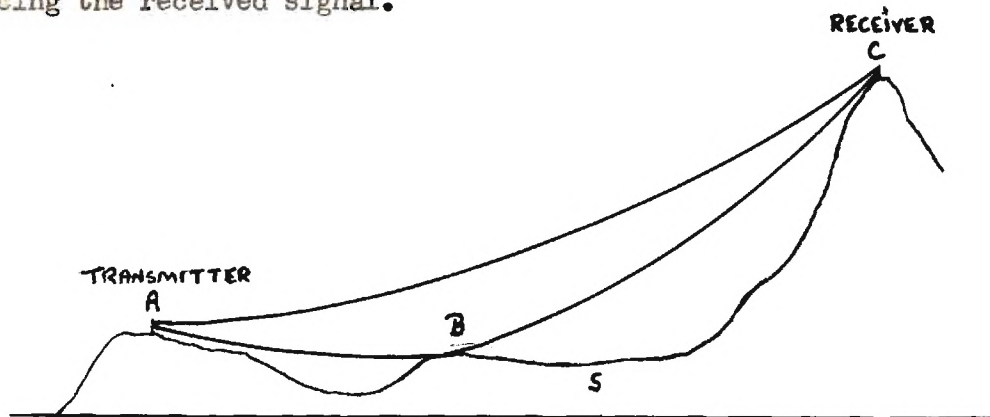


Figure 4. Interference due to surface reflection

The phase difference between the two rays, θ , is a function of the optical path difference, ΔL , the wave length, λ , and a possible change of phase upon reflection, thus:

$$\theta = 2\pi \frac{\Delta L}{\lambda} + \phi$$

where ϕ is a constant.

Over the broken, tree-covered terrain along the propagation path from Georgia Tech to Mt. Oglethorpe, specular reflection from the surface is highly improbable and random scattering of the lower ray would probably result. But suppose the surface S of Figure 4 were the top of a substandard stratum such as might occur in a radiation fog. The ray would then be deflected upward by this stratum and might reach the receiver, where two-path interference would take place.

Any change in the altitude of the top of the layer or any change of the M-gradient through which either ray was traveling would then result in a change in optical path length, and thus a change in phase at the receiver.

Thus if there should be a change in the optical path difference between the two rays, there would be successive reinforcement and cancellation between the two, and the received signal intensity would fluctuate at a rate inversely proportional to the wave length. Circumstantial evidence supports this in that the observed frequency of fluctuation is actually directly proportional to the frequency of the signal.

A similar interference between two or more components of a transmitted signal may also be expected under other conditions. Irregular leakage through a low level duct or superrefractive stratum may provide

several paths of different lengths for the signal components to travel from transmitter to receiver. Similarly, trapping in an elevated layer (see Figure 5) might give rise to interference patterns.

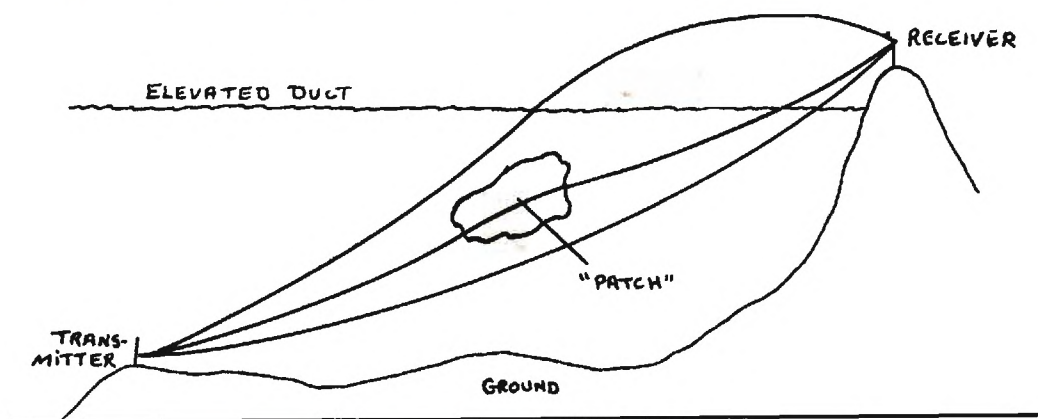


Figure 5. Interference due to elevated inhomogeneities

In most instances, due to turbulence and terrain irregularities, a smooth substandard or superrefractive boundary is unlikely, and it is believed that any interference is then due more to the bending of the rays through the large scale inhomogeneities present in the atmosphere under these conditions. In the case of a heavy, localized rainshower, for example, the fading of the signal is probably due less to the shallow surface duct which is formed and more to the multiple-path interference made possible by inhomogeneous patches present under shower conditions. In the case of low lying fog the effect on the signal may be due less to trapping in the superrefractive stratum above the fog layer, and more to the upward deflection of the signal and resulting interference provided by the substandard M-gradient through the fog itself.

Irregular leakage through a low superrefractive stratum may lead to interference at the receiver between components random in phase and in amplitude. Combined with the trapping of the signal which would also be present under these conditions, this would usually result in a widely

fluctuating received signal with an average intensity somewhat below the calculated free space value. This type of signal has often been observed under conditions of radiative cooling, where the lower layers of air would be highly superrefractive.

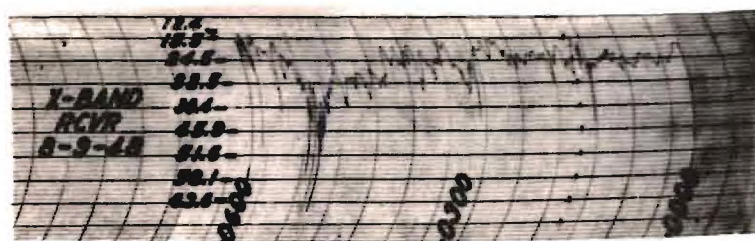
III. EFFECT OF TYPICAL M STRATIFICATION ON THE RECEIVED SIGNAL

Occasionally the weather conditions along the propagation path were relatively uniform and remained so over a sufficiently long interval of time to enable the theoretical behavior of the received signal to be checked by actual observation.

A few instances of signal characteristics under definitely known weather conditions are indicated in Figures 6(a) and 6(b).

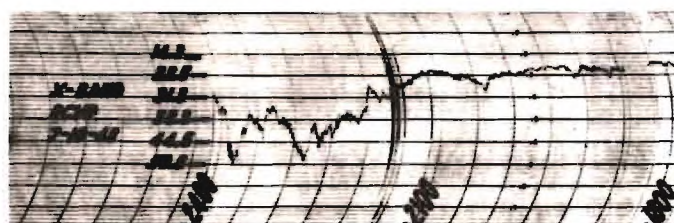
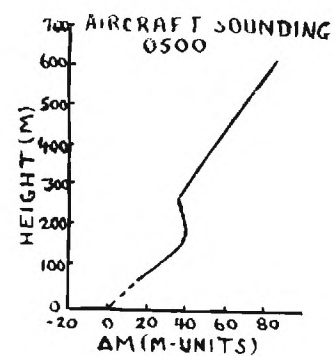
The first strip is the trace of the S Band received signal intensity on the night of August 8-9, 1948. Clear skies and radiation fog predominated along the path and the M-curve, as indicated, was substandard in the lower layers. The signal fluctuations strongly suggest an interference pattern. The average signal level is well below the calculated free space value.

In the late afternoon and night of the 10th of July, 1948 a very intense rainshower activity was centered over the propagation path. Instability and turbulence combined to create large scale horizontal inhomogeneities, with a shallow surface duct due to the wet ground. The effect of this condition on the X Band signal is indicated in Figure 6(a)-2, the fluctuation and drop in signal level being attributed primarily to attenuation of the signal by the rain itself, and partly to interference and surface trapping and scattering. The S and L Band signals were steady, indicating that attenuation is almost negligible at these wave lengths.

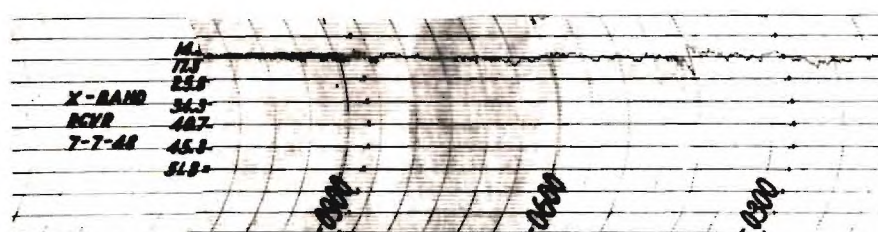
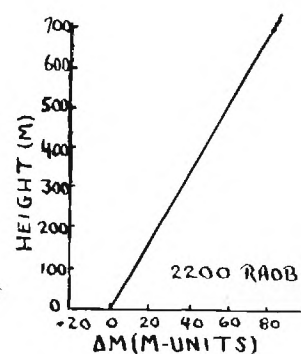


CALCULATED FREE SPACE SIGNAL LEVEL 18.7 DBM

Radiation Fog--August 9 1948

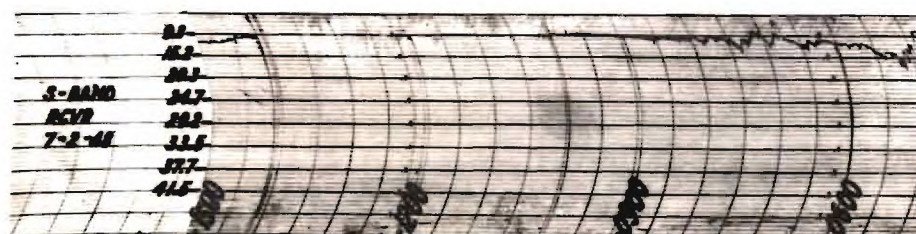
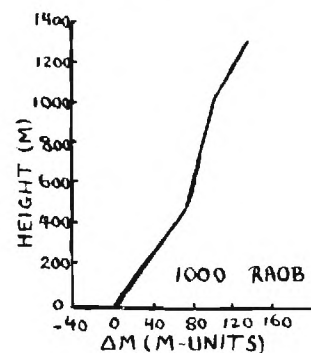


Heavy Rainshowers--July 10 1948



CALCULATED FREE SPACE SIGNAL LEVEL 18.8 DBM

Superrefractive Layer Near Receiver--July 7 1948



CALIBRATION

CALCULATED FREE SPACE SIGNAL LEVEL 8.3 DBM

Standard Atmosphere--July 2 1948

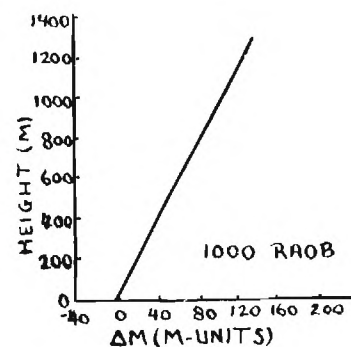
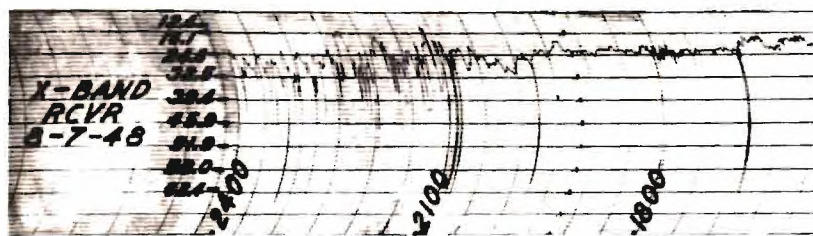


PLATE 6a. RECEIVED SIGNAL STRENGTH UNDER TYPICAL WEATHER CONDITIONS

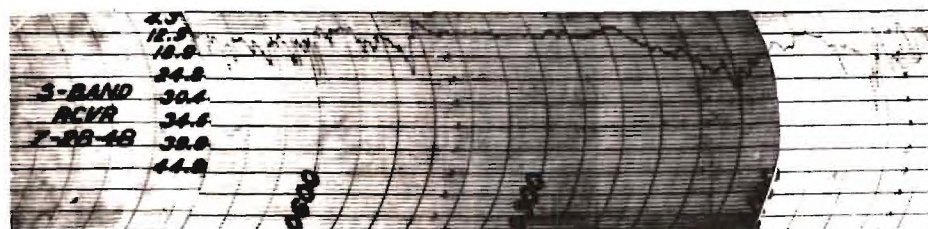
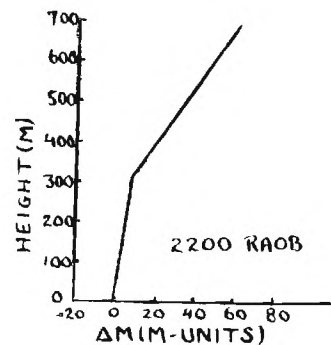
(Signal strength represented in db below 1 milliwatt)

23(b)



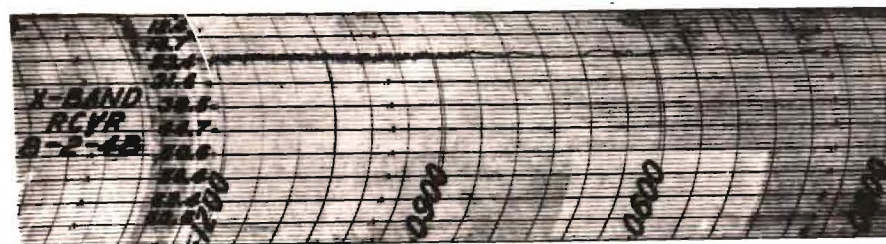
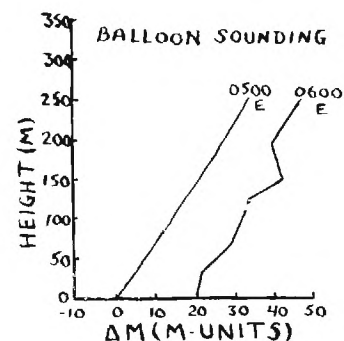
CALCULATED FREE-SPACE SIGNAL LEVEL 18.7 DBM.

Radiative Cooling, Ground Duct--August 7 1948



CALCULATED FREE-SPACE SIGNAL LEVEL 8.8 DBM.

Ground Duct Disrupted By Wind--July 27-28 1948



CALCULATED FREE-SPACE SIGNAL LEVEL 18.7 DBM.

Frontal Fog--August 2 1948

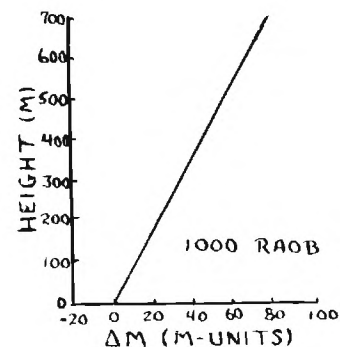


PLATE 6b. RECEIVED SIGNAL STRENGTH UNDER TYPICAL WEATHER CONDITIONS

(Signal strength represented in db below 1 milliwatt)

The M-curve obtained from the Atlanta Weather Bureau was standard, indicating the spotty nature of the activity.

A superrefractive stratum in the form of a subsidence inversion was located near the receiver level on July 7, 1948, from 0000 E to 1200 E. (Figure 6(a)-3) The air beneath was nearly standard. A relatively high, steady signal was received indicating the possibility of some waveguide action by the superrefractive layer, with a minimum of interference.

A standard M-gradient was observed on July 2, 1948, from 1000 E to 1800 E, with clear skies and light winds. The signal (Figure 6(a)-4) was steady and very near the calculated free space value.

Strong ground duct activity due to radiative cooling took place on the night of August 7, 1948, beginning at 1700 E. No fog was reported, and the duct built up to a height of 120 meters above the ground by 2000 E. The resultant trapping, accompanied by irregular leakage and possible interference led to the signal trace in Figure 6(b)-1.

The effect of wind on a radiative cooling duct is illustrated in Figure 6(b)-2. On the night of July 27-28, 1948, a strong duct had begun to form and the signal had begun to fluctuate and weaken. The skies were clear with only a light wind. However, about 0100 E a stiff breeze sprang up, and the resultant turbulence lifted and dissipated the stratum, leaving a near standard M-gradient and a signal level near the calculated value. The fluctuations vanished and the signal became very steady. By 0600 E the wind decreased and the duct activity began again.

As a final illustration, Figure 6(b)-3 indicates the received signal trace during the morning of August 2, 1948, when a heavy frontal fog had blanketed the area, accompanied by light drizzle. The M-gradient, it will be

noted, was very nearly standard, and the signal was steady and near free space. This type of meteorological condition has been observed to persist, often for days at a time, and throughout the whole period the signal received on all three bands was of this type.

IV. DIFFICULTIES INVOLVED IN DIRECT ANALYSIS

Under most conditions such a direct analysis of the effect of weather on the signal is impossible because usually the signal is being affected by several meteorological elements simultaneously. A given stratum, far from being a smooth, steady layer, will probably be broken and ragged, possibly undulating due to a wind shear with height. An irregular stratum of this type would affect the signal differently at different points along the path.

In brief we may say that the effect of a given stratum on the transmitted signal as predicted by the foregoing theory will be modified by the terrain, by the intensity of the stratum itself, and by the extent to which the stratum covers the entire propagation route. However, these factors depend in an intricate way upon each other. For example, everything else being equal, a night time cooling duct would be much more intense over smooth ground than over hilly, broken ground. The turbulence introduced in the latter case may serve to disrupt the duct entirely. Also changes in the M-gradient may cause the transmitted ray to behave differently relative to the surface contours, striking them at different places and at different angles, thus bringing about a further change in the effect which the M-gradient itself exerts on the ray.

To determine the M-gradient at all points along the propagation path involves finding the temperature and moisture lapse rates at all

points, a task which would be extremely impractical if not impossible. The temperature at a given altitude depends upon the season of the year, upon the time of day, upon the type of air mass involved and upon all of the modifications which have taken place in that air mass since its formation. It depends upon latitude, upon wind conditions, upon the type of air which may be overrunning the lower air mass, and upon the terrain-- hills, creeks, wooded or industrial areas, etc.-- along the transmission path.

The moisture at a given level depends upon these same factors and, in addition, the moisture and temperature depend upon and affect each other. Due to this implicit relationship neither temperature nor moisture can be determined without knowing the other, except by direct measurement.

Further, even if we were successful in finding the temperature at, say, 500 ft above the transmitter, this value would hold only at that one point. The temperature at the same elevation but over some other point along the path would be different due to such variables as turbulence, surface moisture conditions and terrain. Similarly a complete sounding over one point on the path is not representative of the air over the entire path.

In brief it is believed that the difficulty of analysis is due less to the ability to predict how a given weather condition will affect a given signal, and more to the difficulty of knowing just what weather conditions exist along the path at a given time. For example, the effect on the signal of a duct due to night time cooling is reasonably well known from observation. The problem then becomes one of estimating the strength and the path coverage of one particular duct on one particular night.

Although it is to be hoped that in the future enough data may be

obtained to make a point to point analysis at least qualitatively practical, at the present time the difficulties presented over a land path are insurmountable⁷.

⁷ In a later operation between Georgia Tech and Lost Mountain in August 1949, hourly soundings through the lower levels of the atmosphere were made by means of wet and dry bulb thermistors attached to a 100 ft tower erected near the middle of the route. This data, combined with frequent surface observations at both receiver and transmitter, permitted much more accurate breakdown and analysis of weather conditions. The relative briefness of the operation, however, prevented the accumulation of sufficient data to warrant a statistical study.

CHAPTER III

STATISTICAL ANALYSIS

I. WEATHER FLOW CHART BREAKDOWN

The overall result of the assimilation of all available meteorological data was a series of fairly complete surface observations and several soundings each day. The radiosonde soundings were the only ones which covered the entire vertical height of the transmission path, but in many cases the M-curves thus obtained were not dependable due to the small number of readings taken in the lower levels of the atmosphere. And in any case the few soundings available could give only a spotty picture of any dominant stratification.

In order to visualize better the changing meteorological elements, a "flow chart", as illustrated in Figure 7, was developed. Plotting height versus time, the weather changes and the positions and changes in the M-gradient stratification were shown in smooth flowing continuity. Meteorological theory was used extensively in the preparation of the flow charts, backed by the soundings and surface observations at the several times each day when they were available.

The flow charts had the advantage of permitting a quick breakdown into time periods during which similar weather conditions prevailed. Periods were noted, in particular, when atmospheric stratification became evident, and these strata, evaluated as to their M-gradients, were indicated as superrefractive or substandard layers. The maximum hourly fluctuations in received power are also included in Figure 7 for reference, measured in decibels.

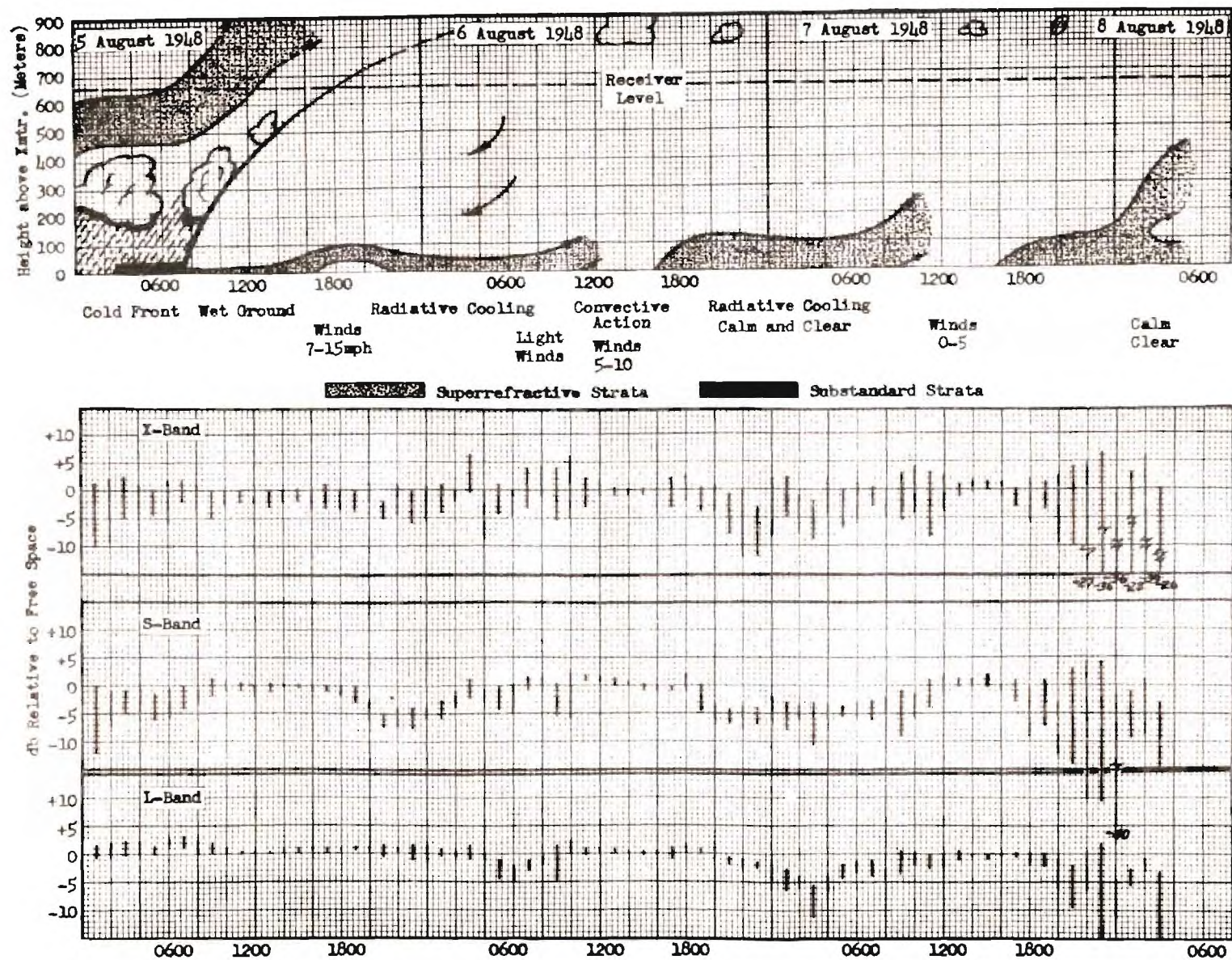


Figure 7.

Weather Flow Chart and Hourly Signal Variations for 5-8 August 1948

During the indicated period in August of 1948 the weather was characterized first by the passage of a cold front on the morning of the 5th, with rain, fog and low clouds in the frontal zone. After passage the air mass discontinuity moved aloft but involved ~~no~~ superrefractive activity since the cold air was relatively dry. The warm air above it thus introduced an increase in vapor pressure and a tendency toward a sub-standard stratum. A shallow "wet ground" duct, with associated air mass inhomogeneities, was evidenced after frontal passage, merging, as the skies cleared on the night of the 5th, into a radiative cooling duct.

Due to the high wind the ground duct activity on the night of July 5-6 was slight. Turbulent lifting and mixing of the air during the night held stratification to a minimum.

Convective action on the afternoon of the 6th and again on the afternoon of the 7th served to eliminate any remaining strata and to mix the air thoroughly. However on the nights of the 6th and 7th clear skies and light winds encouraged the formation of intense radiative cooling ducts---probably enough cooling to produce fog in low areas along the path, although none was reported at either the transmitter or receiver. The more intense superrefractive activity on the night of the 7th, accompanied by a greater signal fluctuation as well as a weaker average signal level, is probably due to a lighter wind or to drier air aloft. On both nights the sky was almost completely clear over the entire route.

After the weather analysis was completed, the entire propagation period was then broken down and regrouped under the following principal subdivisions:

- (a) Periods during which a superrefractive layer was evidenced, the air above being standard.

- (b) Periods when there was an elevated superrefractive layer only, lying below the receiver level.
- (c) Periods during which an elevated superrefractive layer was near the receiver level, possibly including the receiver.
- (d) Periods when combinations of two or three of the above classifications were observed.

The same breakdown technique was used to isolate and study periods of heavy rainfall, periods of fog, periods of frontal activity and periods of standard M-gradient.

II. PERCENT OF TIME CURVES

The periods thus obtained were then subjected to statistical analysis. A count was made of the number of minutes that the received signal strength was below various levels, and "percent of time" curves were drawn to show, for example, how the X Band behaved over a summation of all periods during which a ground duct was active. These curves (Figures 8-17) indicate on the abscissa the percent of time when the signal strength or the signal fluctuation was below the ordinate. Similar curves were drawn for each of the three frequencies and for each typical meteorological condition.

Percent of time curves may, of course, be drawn to represent any desired degree of breakdown. Figure 8 shows how the X Band behaves under

- (a) all conditions, summed over all operating periods,
- (b) all conditions during all Summer runs, and
- (c) frontal fog conditions during midsummer.

Each successive subdivision is based on data covering fewer minutes

Figure 8. Distribution of Instantaneous
Received Power-X Band.

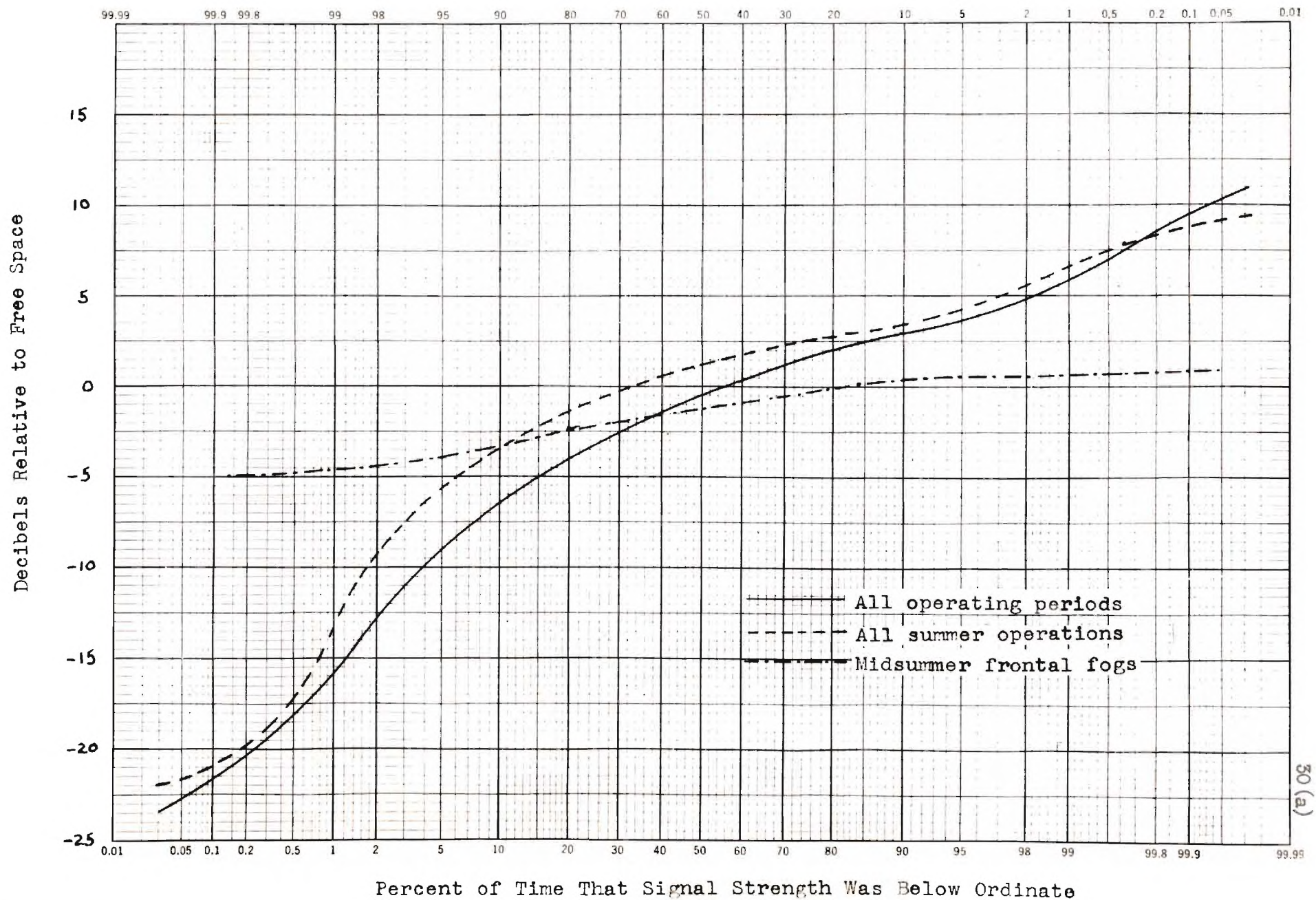


Figure 9. Distribution of Instantaneous
Received Power-S Band.

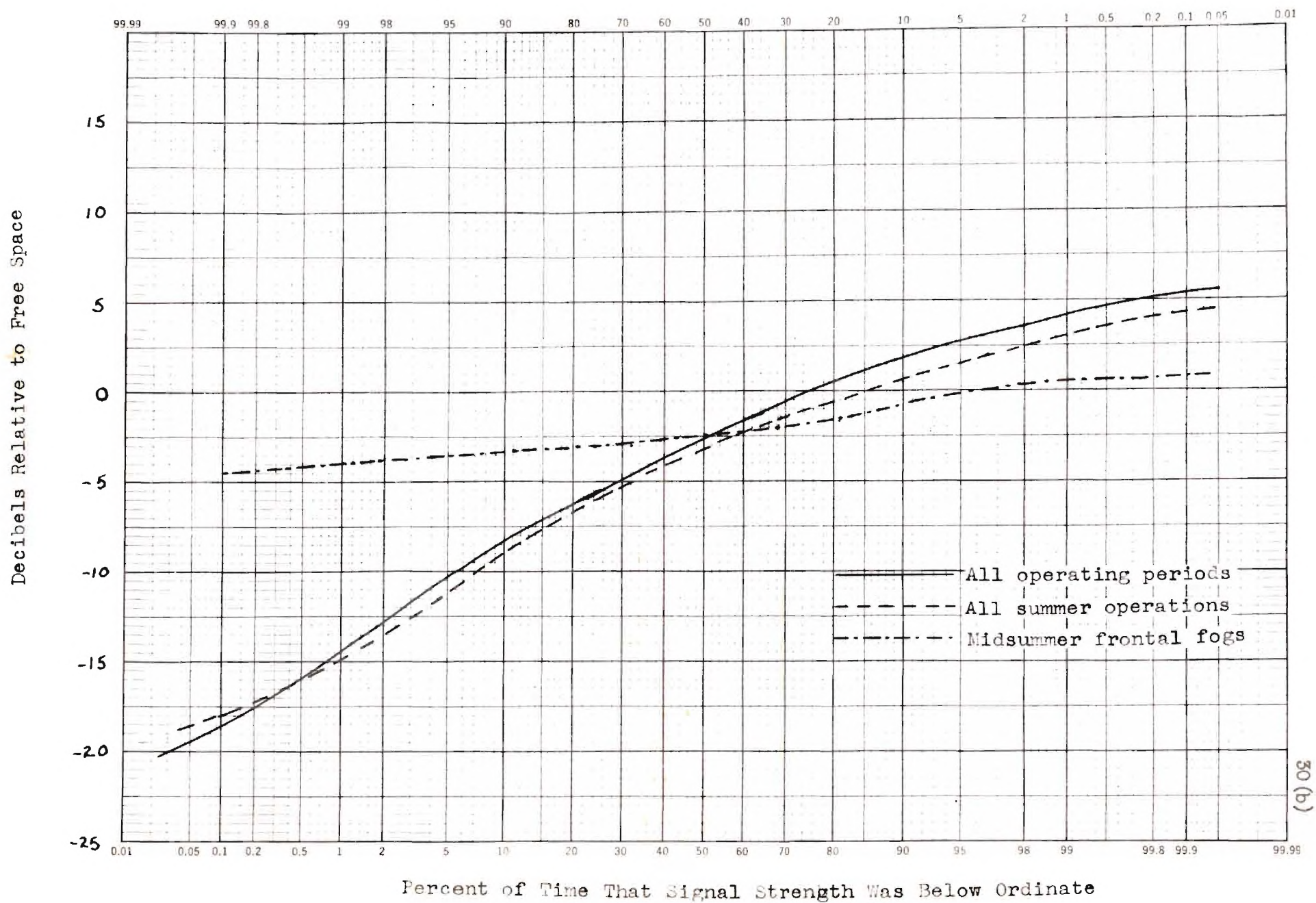
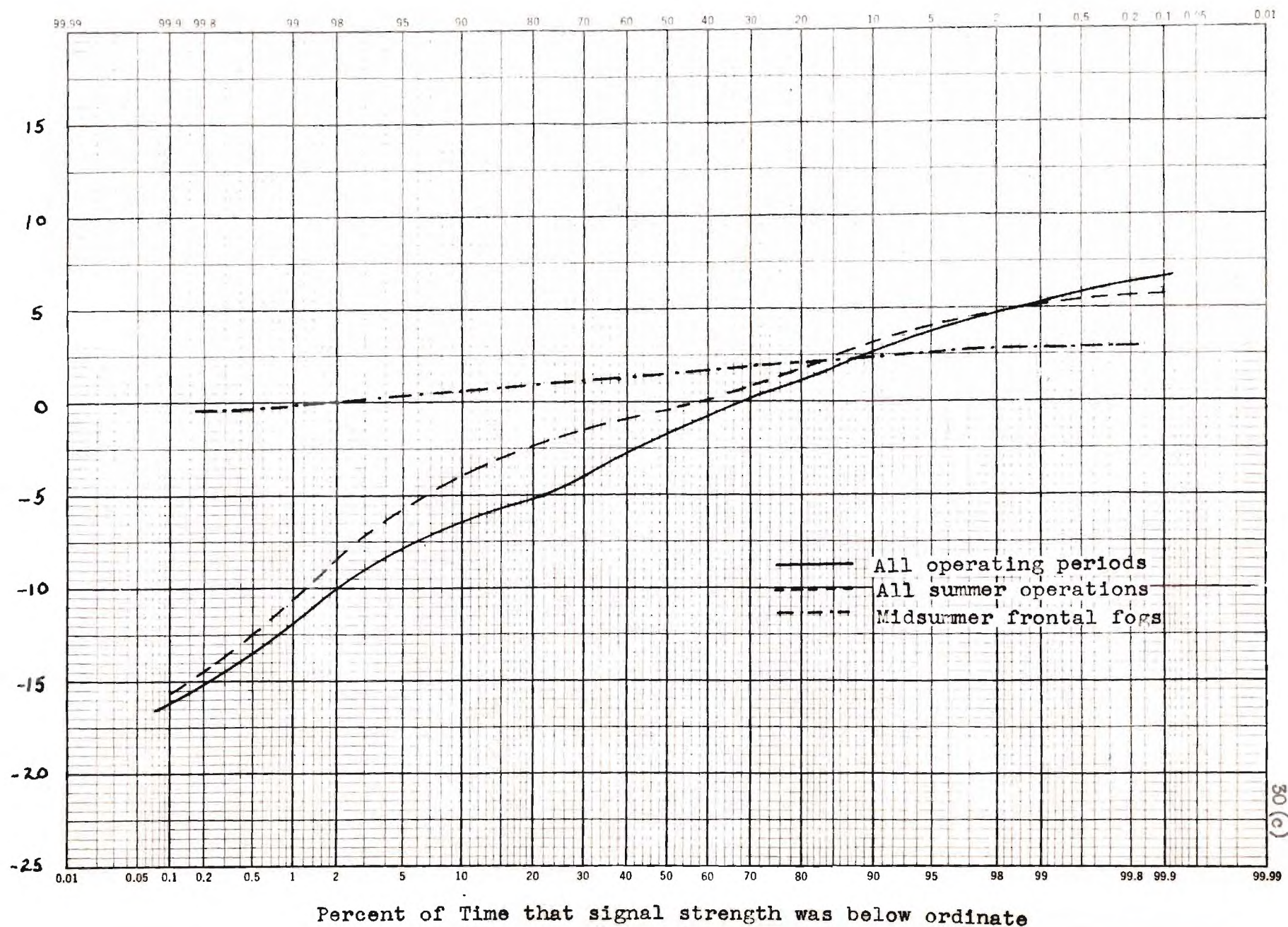


Figure 10. Distribution of Instantaneous
Received Power- L Band

Decibels Relative To Free Space



of operation than the preceeding subdivision, but the final category is still based on enough data to indicate a distinct trend. Figures 9 and 10 indicate the corresponding behavior of the S Band signal and the L Band signal under the same set of conditions.

III. "STANDARD" PERIODS

This analysis of the signal from the standpoint of instantaneous received power is rendered more complex due to the necessity of accurate calibration. The day to day changes in calibration indicate a possible error of about ± 2 db in most readings and a corresponding uncertainty in the resulting percent of time curves. This 2 db, while slight, is still enough to mask small effects or render them doubtful. In several of the earlier operations this uncertainty was increased by the possible error involved in the measured quantities used in the calculation of the free space level. Actual received signals may differ from the free space value due to meteorological strata, terrain irregularities or attenuation.

"Standard" periods were chosen from each operation. These were mid-day periods when no stratification was present and no frontal activity apparent. Convective action had mixed the air along the propagation path so that there was a uniform vertical M-gradient. Since the M-gradient depends on temperature and moisture content, the standard signal may differ from the free space value by an amount depending on the type of air mass involved, on the surface temperature and moisture, or in brief, on the seasons. A comparison of the received signal strength with the standard level for that period will be helpful in evaluating the effect of a given condition.

IV. NON STANDARD PERIODS

In the event of vertical stratification, the effect of a stratum on a transmitted signal depends upon the intensity of the layer and upon its position vertically and laterally along the path. These, in turn, depend upon many elements, principally the following:

- (a) the path coverage, or the fraction of the propagation path along which the stratum is dominant;
- (b) the angle at which the incident beam strikes the layer, which in turn depends upon the height and distance of the layer and upon the M-gradient beneath the layer;
- (c) the M-gradient through the layer itself;
- (d) the depth of the layer;
- (e) any associated attenuation introduced along the route.

Exact measurement of these conditions is impossible. However, certain assumptions can be made which we can support statistically.

1. Path coverage for a radiative cooling duct will be greatest and the duct will be strongest for (a) maritime tropical air cooled from below, most commonly found on summer nights; (b) clear sky; (c) small turbulence and (d) wind near 5 mph. If the wind is too light there will be very little vertical development of the duct. If it is too strong the layer may be disrupted. The effect of this type of duct will be to deflect the beam downward, or, as the duct builds up to include the transmitter it may trap part of the energy. This is partially responsible for the wide fluctuation in received power, averaging several decibels below standard. (See "Interference", page 20).

For a wet ground duct, due to the rapid drop in moisture above

wet ground, the greatest effects, as already explained, are caused by the accompanying air mass inhomogeneities when heavy rain falls through dry air. Path coverage will of course depend upon how widespread the shower activity becomes. Since this type of superrefractive stratum is usually confined to a shallow layer close to the ground, it lies below the transmitter and seldom acts as a trapping layer. Multiple-path interference might accompany the activity, however, resulting in a widely fluctuating signal centered about at the standard signal level.

2. Frontal activity or cloud activity will usually affect different parts of the path at different times and at different heights and will seldom give uniform path coverage unless the front stagnates over the area. The effect on the signal will usually be either as a wave-guide, with a superrefractive layer near the receiver level, or else a slight trapping and leakage effect when the layer lies below the receiver. The former condition usually results in a steady signal which may be above free space; the latter results in a fluctuating, depressed signal. In either case the effect upon the signal is not as pronounced as lower stratification would produce since stratification is usually less intense at higher altitudes.

V. INTERPRETATION OF THE VARIOUS PERCENT OF TIME CURVES

The effect of the meteorological elements upon the X, S and L Band received strength is indicated in the accompanying figures.

Figure 11 indicates the effect that the height of a superrefractive layer has upon the received signal. The average received signal level is nearly the same for surface layers and for low level elevated layers lying below the receiver. The principal difference is the amount of fluctuation

in the signal, a layer nearer the receiver level resulting in relatively steady reception.

Figure 12 shows the effect of winds during periods which would otherwise exhibit strong radiative cooling duct activity. As expected, a strong wind tends to mix the various meteorological elements and oppose any stratification. With wind stronger than 15 mph the received signal behaves almost as it does with a mid-day standard atmosphere.

The effect of heavy rainshowers on the various bands has already been described. Figure 13 indicates that the attenuation is much greater on the X Band. It must be borne in mind that there would also be interference and surface superrefraction to consider as well as attenuation, and Figure 13 involves all three of these effects.

The maximum hourly fluctuations of the received power can be analyzed much more readily than can the instantaneous strength. The accuracy of calibration and the calculation of the free space value are not necessary in studying the signal fluctuations, since only the change is considered.

Figure 14 shows the difference between radiative cooling fogs and frontal fogs, or "bad weather" fogs. As explained previously, radiation fogs are usually associated with a substandard M-gradient through the fog layer with a tendency toward superrefraction in the upper boundary due to the abrupt decrease in relative humidity there. In frontal fogs, because of the low clouds, drizzle and generally moist air above and through the layer, the M-gradient is uniform and near standard. Two path interference is unlikely since there is no stratification and no air mass inhomogeneities of any appreciable size. The most pronounced difference between the two types of fog, so far as the signal reception

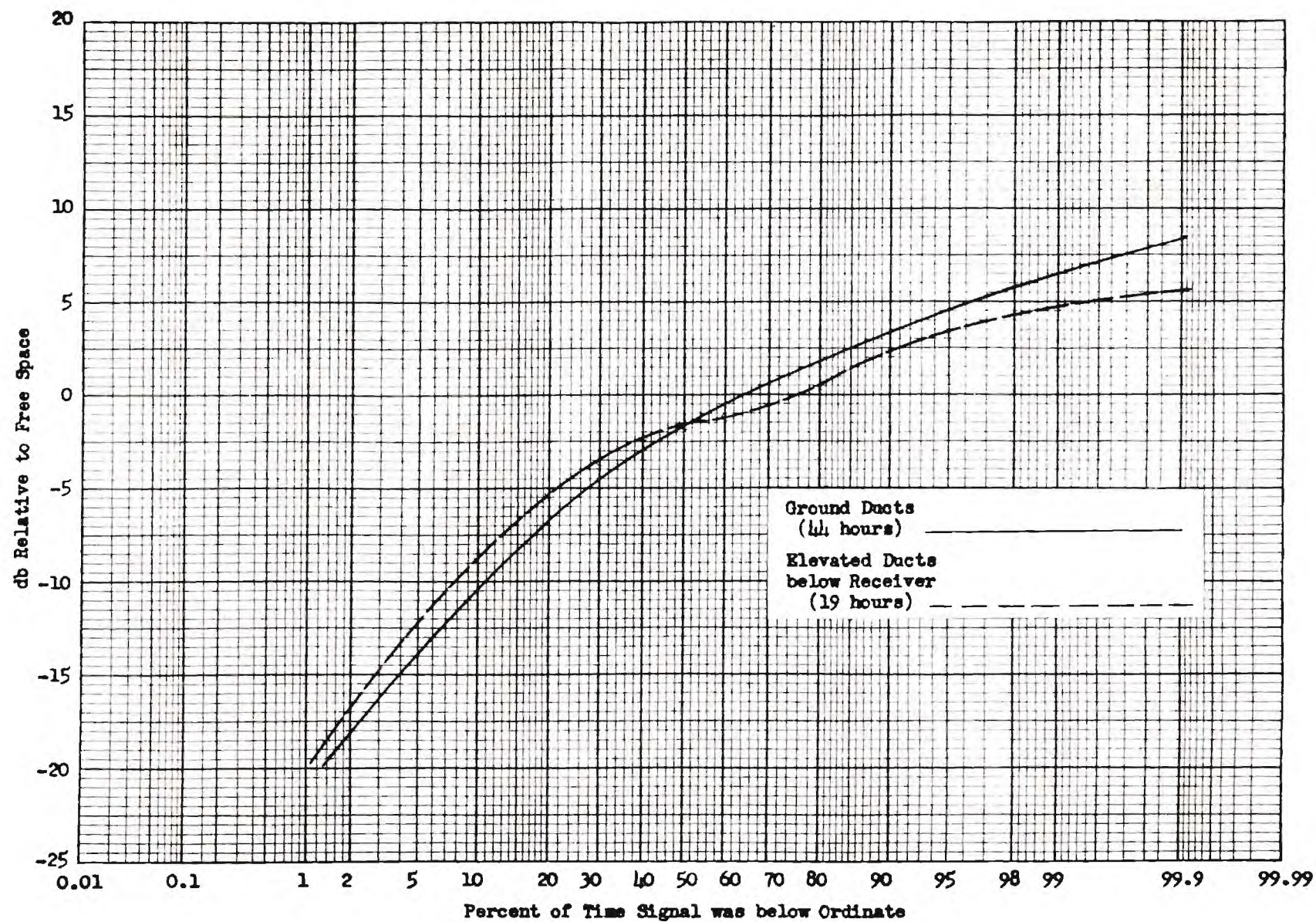


Figure 11

Effect of Ducts on Received Power at X-Band during Period, 27 July - 9 August 1948

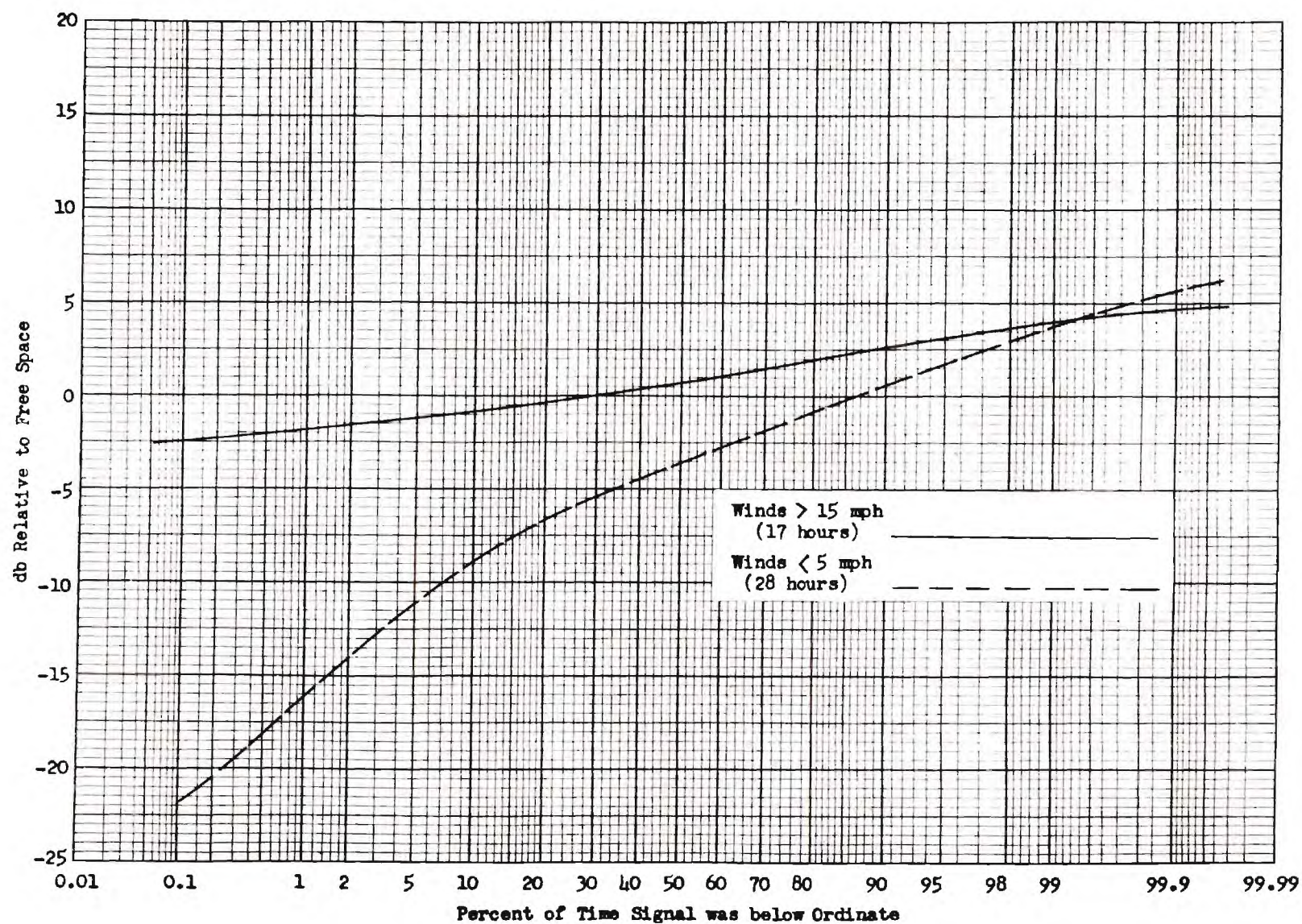


Figure 12
Effect of Wind Speed on Received Power at X-Band during Period, 18 October - 10 November 1947

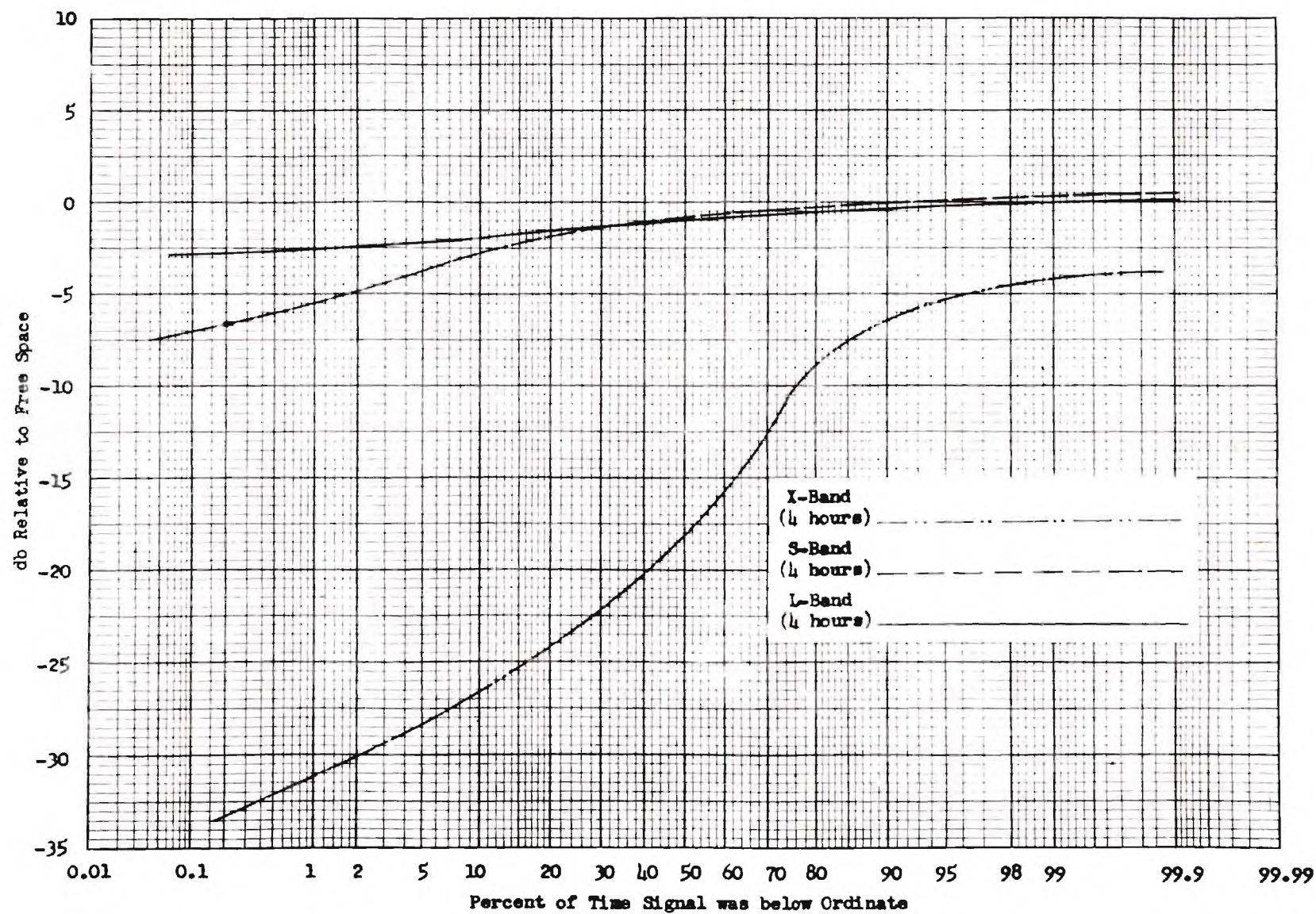


Figure 13

Effect of Heavy Rain Showers on Received Power at X-, S-, and L-Band during July, 1948

is concerned, is the marked difference in the amount of fluctuation they produce. The ordinate on this graph represents simply fluctuations in the received signal in decibels, with no reference as to the actual value of the power received. The X Band, it will be noted, fluctuates 19 db for 50% of the time during radiation fogs. The S Band fluctuates 13.5 db for 50% of the time, and the L Band only 7.5 db.

Figures 15, 16 and 17 indicate the fluctuations in the X, S and L Bands under the influence of various other meteorological combinations. One conclusion is immediately apparent. In all observed conditions, the X Band fluctuates most, the L Band least, just as in the analysis of received strength it was noted that the X Band suffered greatest from rain attenuation. There also the L Band was affected least.

VI. STATISTICAL ANALYSIS OF INDIVIDUAL VARIANTS

As previously explained, the weather data on the Mt. Oglethorpe operations were rather sketchy, precluding a direct analysis. However, an initial effort has been made to investigate quantitatively the effect of each individual variant on the signal.

Let us again consider Figure 8, showing the overall X Band activity for all operating periods, regardless of weather conditions. This curve, by its very nature, must include all weather activity—all the ground duct periods, all the rain periods, all the fog periods, all the seasons. The amount of fluctuation in this curve we may think of as the margin of uncertainty in the location of the received signal level. That is to say, at any given instant the received signal strength may lie anywhere between 25 db below and 10 db above free space, an uncertainty margin of 35 db.

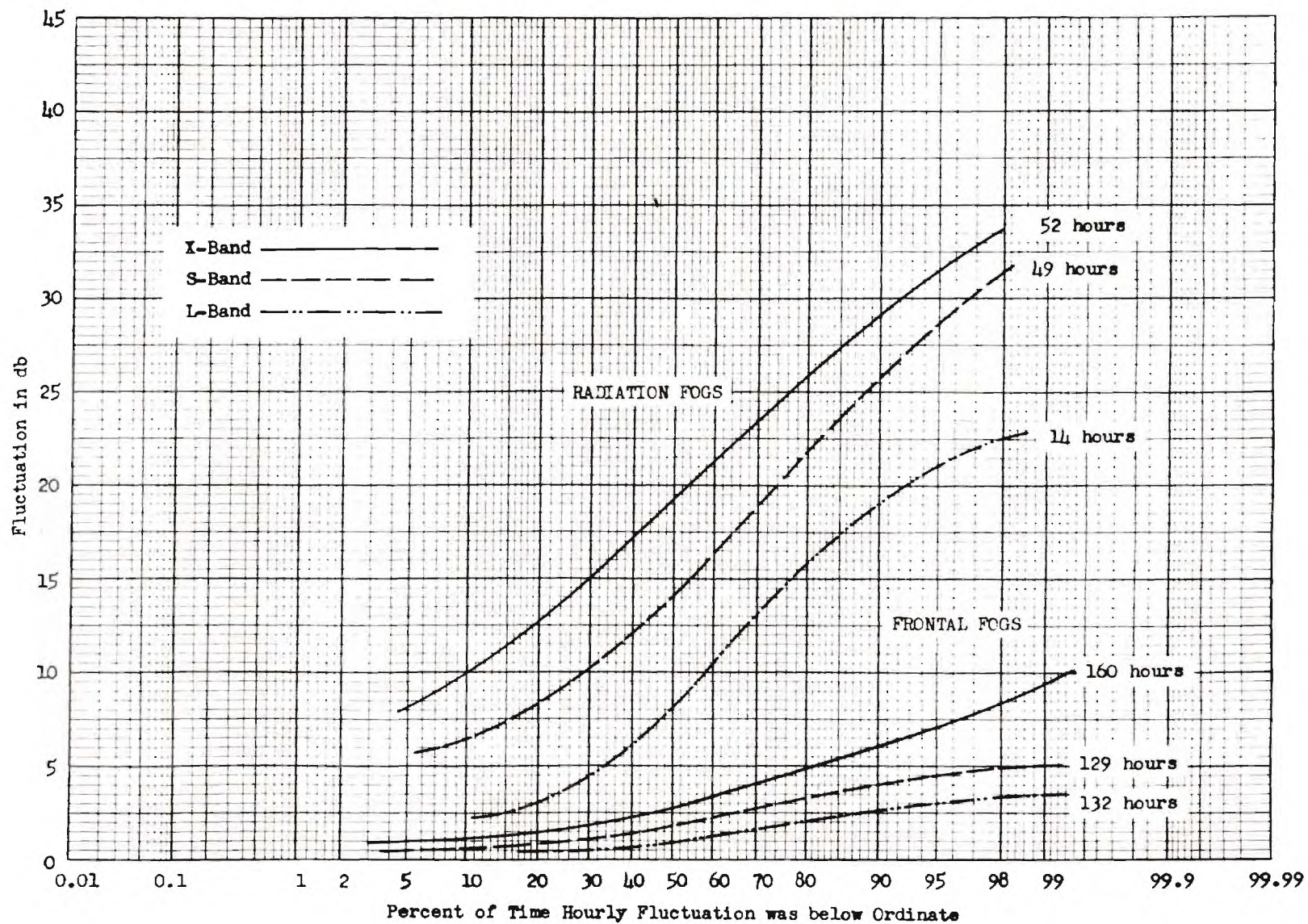


Figure 14

Maximum Hourly Fluctuations of Signal Strength under Fog Conditions

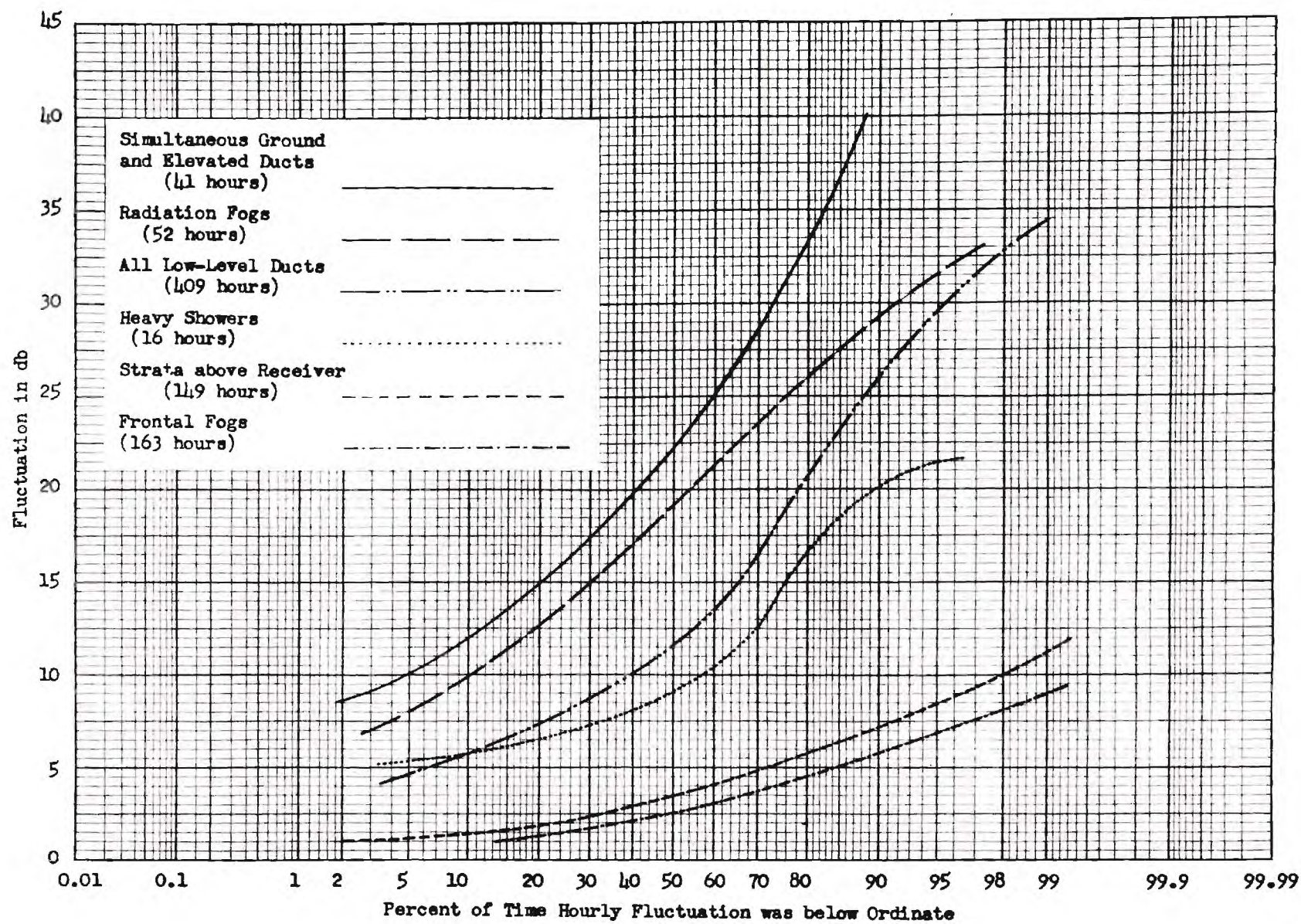


Figure 15
Maximum Hourly Fluctuations of Received Signals at X-Band

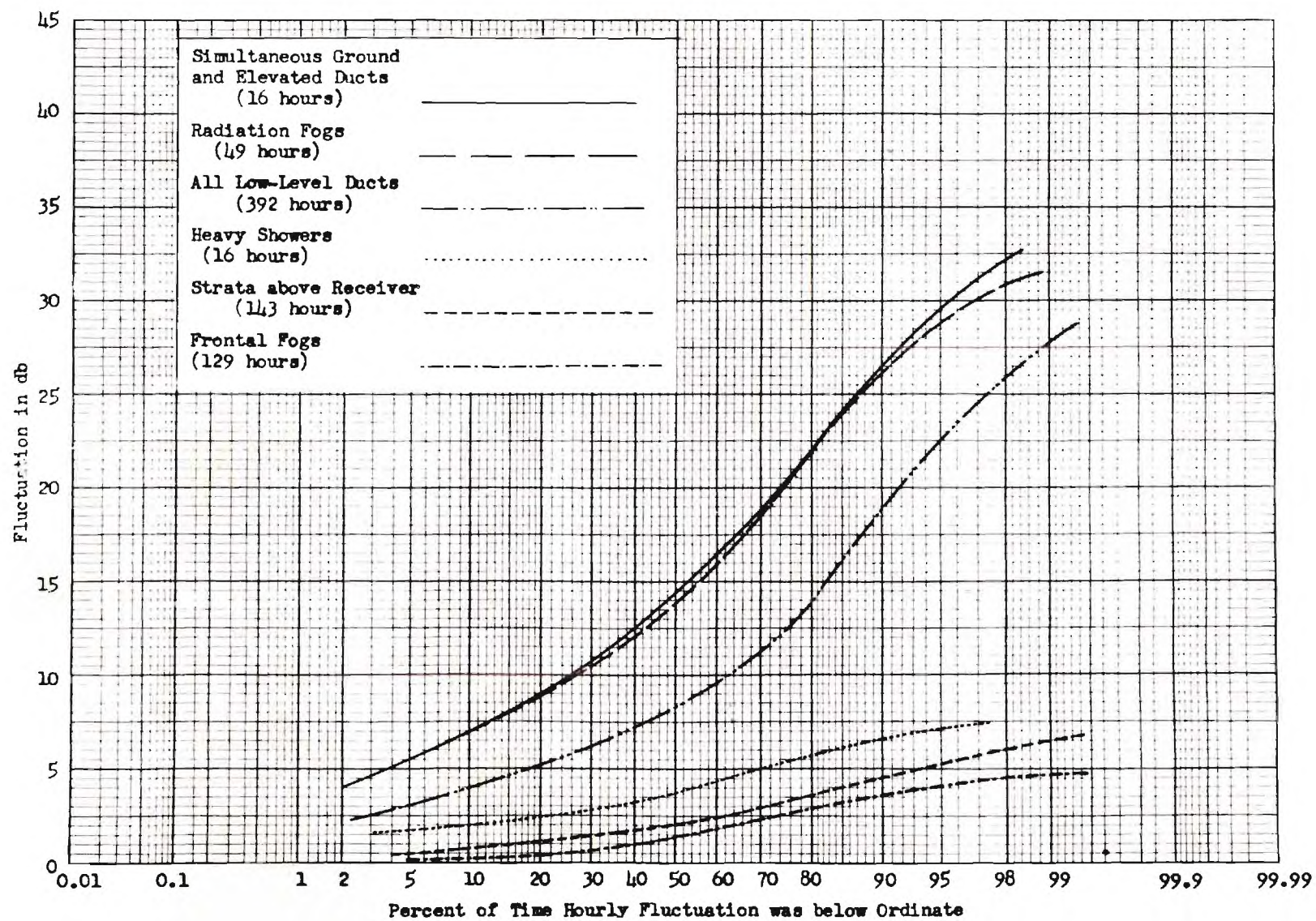


Figure 16
Maximum Hourly Fluctuations of Received Signals at S-Band

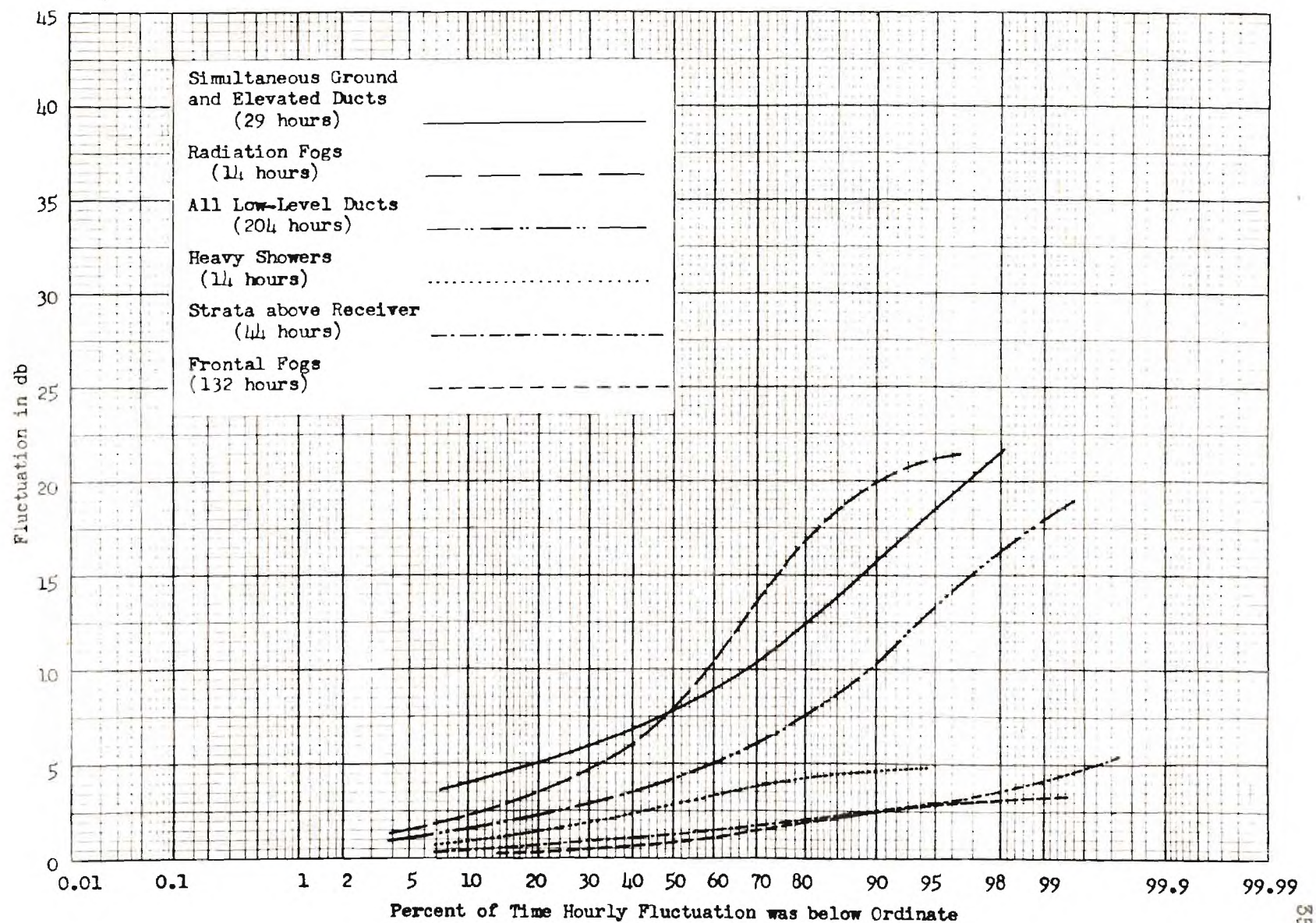


Figure 17

Maximum Hourly Fluctuations of Received Signals at L-Band

If, then, we wish to study the effect of any one meteorological element, say fogs, we can draw such a curve from our flow chart breakdown. Since the first curve included all weather conditions, it must necessarily include all fog periods, so that the new curve will amount to a flattening or narrowing down of the margin applied to the first curve.

Similarly, we may wish to study frontal fogs only. This further restriction on our field of study must therefore result in further flattening of the curve (possibly accompanied by a shift in the average level) since this category includes only a part of that which was included in the curve for all fogs.

We may apply any further conditions we may desire. Frontal fogs in the summer, for example, may be further narrowed down to those periods when it was raining; and further, to those periods when it was raining out of extremely low clouds, or with high winds, or any other set of conditions we wish to impose. Each additional condition will result in a greater accuracy in our location of the received signal level, the extremes of the curve representing the amount of uncertainty involved.

Then finally we will have a curve which will be essentially a horizontal line---indicating, say, that when we have a summer frontal fog with heavy rain and a 200 ft ceiling, and with the wind 20 mph over the path, the received signal power may then be pin-pointed at 10 db below calculated free space. If it is uncertain whether the wind averages 20 or 30 mph over the path, then there will be a corresponding uncertainty, or fluctuation in the percent of time curve.

This consecutive breakdown process we are in a position to utilize roughly from the Mt. Oglethorpe data. At present the extent to which such

a breakdown can be carried is limited by the quantity and accuracy of the data available for statistical study. However it may point the way for a more accurate future analysis, based on more data, such that the received signal could be predicted with an accuracy limited only by our knowledge of the weather along the path. Any fluctuations in the resulting curve, any deviation from a horizontal line, would then be caused by only the uncertainty involved in our knowledge of weather activity and terrain along the route.

VII. SUMMARY

The statistical method of analysis at present seems the only practical approach to the problem of determining the effect of various weather elements on microwave propagation. With sufficiently accurate data this method may be refined to the point where it will give a very accurate indication of the optimum frequency to use under a given weather situation, and where it will give a reliable prediction as to how a signal of that frequency will behave.

At present, with the data available from the Oglethorpe operations, only statistical conclusions may be drawn. Quantitatively our results are subject to the errors present in our evaluation of the weather and to the need of a greater mass of data. We can safely predict that under conditions of ground duct activity all bands will fluctuate, that the X Band will fluctuate most, the L Band least. We can predict a steady signal level when frontal fog envelops the area or under standard atmospheric conditions. We can expect a weakened, fluctuating signal to be associated with radiation fog, again the longer wave lengths being affected least.

But when we attempt to say how much effect each condition will have on the received signal, we are immediately confronted with the fact that we cannot at present know the weather along the path with sufficient accuracy to warrant a valid statement. The exact decibel level which a received signal will seek must remain shrouded in doubt until such time as a greater quantity and a greater accuracy of meteorological data may be secured.

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